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A NATURAL GAS EXPLOSION NEAR WALDRON, IND.

Introduction.—On the eleventh day of August, 1890, a natural gas explosion of much violence occurred near Waldron, in Shelby county, Indiana. The ground was disturbed, and fractures, crevices, and craters were formed over an area of several acres.

Many newspaper accounts of the explosion were published. In most cases these were greatly exaggerated. Bare mention of the occurrence was made by E. T. J. Jordan, natural gas supervisor of Indiana, in his report to the state geologist, in 1891.[1]

In discussing a violent natural gas explosion that occurred at Coffeyville, Kan., on July 26, 1894, Haworth refers to a similar explosion that had occurred in Indiana, giving the locality as Kokomo; he says:

> One similar occurrence is known in the gas field of Indiana, near Kokomo, in which a fissure was formed in the solid limestone from which natural gas escaped with explosive violence and caught fire from a burning log heap near by.[2]

Haworth refers here to the Shelby county explosion, which did not occur near Kokomo, however, but took place about one hundred miles south and slightly east of that city. Neither was a visible crevice formed in solid limestone, as the explosion occurred in an area that was covered with soil and gravel, though

[1] *Indiana Department of Geology and Natural Resources, Seventeenth Annual Report*, p. 338. Indianapolis, 1892.

[2] *Kansas University Quarterly*, Vol. IV, p. 95. (Mr. Haworth's information concerning the Indiana explosion was obtained from Mr. William Moore, of Kokomo.)

limestone crops out near by (at *L. S.* Fig. 1) and also ¼ mile up stream from the area of the main explosion.

Later (1899), in a report upon the Waldron shale, made to the state geologist of Indiana, Mr. J. A. Price states briefly such facts concerning the Shelby county explosion as could be gleaned from statements of the citizens of the neighborhood at that time.

Except for the brief notices mentioned above no account of this interesting explosion has appeared in any scientific publication, so far as the writer is aware, and it is with a desire to place on record the salient facts concerning it that the following map, figures, and paper are published at this time.

The writer visited the locality on August 15, 1890, four days after the explosion occurred, while its effects were still fresh, and while the gas escaping from the crevices and craters still burned intermittently when ignited. From notes taken at the time, a map was prepared and a short account of the explosion was written, and read on November 7, 1890, before the Indiana University Scientific Society. The map and facts of the present paper are taken from the paper read, but not published at that time.

The figures are reproduced from photographs obtained from J. T. Schaub, Hope, Ind., and Everett Ayers, of Germantown, Ind.

Location.—The explosion occurred near the center of section 7, 11 north, 8 east; the affected area is two and a half miles south, slightly west of the village of Waldron, and two and a half miles west, slightly south of the village of St. Paul. Gas wells were reported to be producing at the time from both of these villages.

Owing to the fact that the Ogden Cemetery was at the edge of the disturbed area, the outburst of gas was known locally as the Ogden Cemetery "earthquake," "gas explosion," and "blow-out."

A total area of about ten acres was affected. The most violent explosion was limited, however, to a space of about two acres at the east side of the locality affected, and is shown approximately by the Nos. 1, 3, 5, and 6, Fig. 1. The topog-

raphy and relations of the area can be best understood by reference to Fig. 1.

The area that was shaken up lies at the south side of Big Flat Rock River or Creek, in an almost half circle bend formed by that stream, and is comparatively flat creek "bottom land"

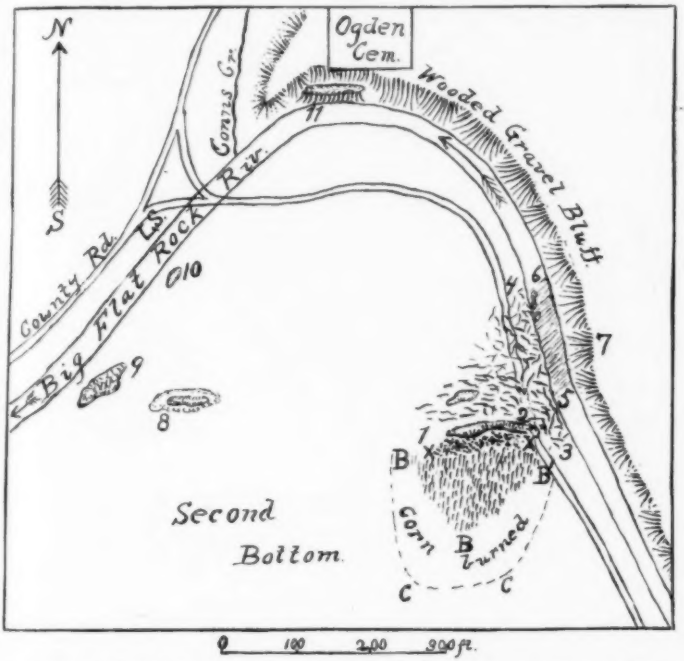


FIG. 1.—Map of the area affected by the Ogden Cemetery gas explosion, in Shelby county, Ind.

made up of alluvium. The south side of this area, marked "second bottom," (Fig. 1) is slightly higher than the portion, included by the Nos. 4, 3, 1, 8, 9, 10, and 11, in which the explosion occurred. At the time of the explosion growing corn covered the second bottom.

At the east and north side of the stream is a wooded bluff, of glacial gravel and clay, about forty feet high; this bluff was

covered with forest trees at the time of the explosion. There were also a few trees of considerable size bordering the creek on the side across from the bluff.

Geologic relations.—Most of the area affected by the explosion is covered by alluvial soil or gravel; only one exposure of rock in place occurs (viz., at *L. S.*, Fig. 1). Rock in place (belonging to the Niagara group) outcrops one-fourth mile up stream from the area of the main explosion, and in the affected area the limestone is probably only ten or twenty feet below the surface. The strata of this region lie approximately flat.

The rocks which underlie the region are shown by the following section of the strata passed through in drilling the gas well at C. J. Bickhart's mill, about two miles east of Ogden Cemetery.

SECTION AT BICKHART'S MILL.[1]

1.	Clay	4 feet
2.	Limestone (Niagara, in part at least)	86
3.	Shale (Hudson River)	774
4.	Limestone (Trenton)	22
	Total	886

Gas with a pressure of 335 lbs to the square inch was struck at nine feet in the Trenton limestone.

An irregularly bedded, porous conglomerate which gives off a fetid odor from a freshly broken surface is exposed for 150 feet along the east bank of the river about 150 yards above the area in which the main explosion occurred. This conglomerate is made up for the most part of coarse sand and small pebbles, but it contains some bowlders at least eight inches in diameter; it dips 30°, N.30°E., and is overlain by soft glacial clay and gravel. This is probably a locally hardened glacial deposit, and, if there is any connection between it and the gas explosion, that connection is not apparent to the writer.

Character and results of the explosion.—The explosion occurred about 9 o'clock, on the morning of August 11; it does not appear to have been accompanied by any violent report, for the attention of the people living in the neighborhood was first

[1] Reported by C. J. Bickhart in 1902.

FIG. 2.—View up the river from near the point 4 in Fig. 1. The county road which was made impassable by the explosion is seen at the right of the center of the picture. The trees that are barren of leaves had their leaves and smaller twigs burned off. The trees at the left of the picture are on the east side of the river and had their leaves browned by the heat. Most of the people in the background are standing on the earth blown out at the south side of the main fissure, x–x^1, Fig. 1. Blown down corn is barely shown at the right end of the picture. At the left end trees blown down by the explosion are shown, as is also the elevated bottom of the creek, where water stood prior to the explosion. From a photograph taken August 12, 1890.

attracted by a roaring or whizzing sound like the escape of steam from a boiler, but much louder. Upon looking toward the river, a sheet of flame was seen extending about 250 yards along the east side of the river bend. Regarding the height of the flame, estimates of those in sight at the time varied between 150 and 300 feet or more.

The height and intensity of the flame were sufficient to sear the leaves on the trees standing on the gravel bluff east of the river, and to completely burn off the leaves and small twigs from the trees standing near the fissures through which the gas escaped.

The vegetation around the openings (8, 9, 10, Fig. 1) at the west side of the area showed that the gas that escaped from those openings did not burn.

The roaring and flame continued at their height for about fifteen minutes, and then gradually subsided, and the gas burned from only a few of the crevices that had been formed.

The explosion had opened up a great number of crevices in the soil near the river bank (3–4, Fig. 1. See Fig. 2 also). When the ground was visited by the writer, these fissures varied in width from a few inches to four or five feet, with a like variation in depth, the shallowness being caused by the caving in of the soft soil at the sides and from the top.

Some of the fissures had evidently been formed by the upheaval, or depression, of the surface which had been elevated in some places, and in others had sunk down as much as four or five feet. The larger fissures, however, showed that they had been formed by the soil being blown out from below, the blown-out material being piled up at the sides of the fissures.

The character of the fissures is shown by Fig. 2, which shows also the "heaved up" condition of the surface. The center of the public road is shown in the foreground at the right side of Fig. 2. At this place (corresponding to the point 2 in Fig. 1) the road was so twisted and fissured as to be impassable.

The river bed from 5 to 6, Fig. 1, had been raised several feet, leaving the bottom exposed where water had stood before, while the west bank of the stream, from 3 to 4, Fig. 1, had sunk

several feet. It was reported that the river flowed into the crevices between 3 and 6, Fig. 1, for some hours after the explosion.

Forest trees near 3, 5, and 11, Fig. 1, had been blown up by the roots and blown several (10–20) feet from where they had stood. The leaves on the trees and bushes from 5 to 11, Fig. 1 (about two hundred yards) were seared by the heat. On the west side of the creek from *B'* to 4 the smaller branches (and in some cases the bark) of the trees were entirely burned off.

FIG. 3.—View from the east side of the stream below 7, Fig. 1, looking westward across the river towards the point where the explosion was most violent. The trees shown in the water were blown up by the explosion, as were also the piles of earth along the river bank on which the figures stand.

Many of the trees were completely plastered from bottom to top with a fine mud, unlike anything exposed at the surface. This mud must have been thrown out with great force, as was shown by the manner in which it was plastered upon the trees and corn of the affected area. Lying about the fissures and over the surface were large quantities of this mud, which, upon drying, hardened somewhat and was easily cut into various designs, which were sold as souvenirs to visitors who came in great numbers to the locality.

Examined under the microscope, this mud is seen to be composed of an impalpable powder, such as might have been formed by direct precipitation of its constituents from solution.

ANALYSIS OF THE MUD BLOWN FROM THE CREVICES.

A. J. Cox, analyst.

	Per Cent
Lime (CaO)	13.4
Magnesia (MgO)	4.30
Iron oxide (Fe_2O_3)	15.45
Silica and insoluble silicates	49.75
Carbon dioxide (CO_2)	12.10
Water	5.6
Total	100.6

When seen by the writer, the principal fissure formed by the explosion (see 1, 2, Fig. 1) was between fifty and one hundred feet long, about five feet wide, and five feet deep. This crevice had evidently been much deeper, but when the gas ceased escaping under sufficient pressure to keep it open, loose earth had caved into it and partially filled it. The fissure extended almost east and west, and was along the foot of the slope, between the second bottom and the lower ground. At its south side was a mass of earth, x–x', from five to ten feet high, that had been blown from the fissure.

A field of corn was growing south of the main fissure at the time of the explosion. About an acre of this corn, *B*, *B'*, *C*, *C*, Fig. 1, was burned brown by the heat, while half of this burned portion, *B*, *B*, *B'*, Fig. 1, was blown flat upon the ground, and much of the blown down corn was plastered with mud. The corn was blown over toward the south, showing that the force came from the fissure at the north side. Some of the blown down corn is shown at the right end of Fig. 2.

At 11, Fig. 1, a slice of the gravel bluff was shaken down by the explosion, and some trees were blown up by the roots.

Irregular openings or craters were blown out at 8, 9, 10, Fig. 1, but the explosion was not so violent here as at the east side of the affected area.

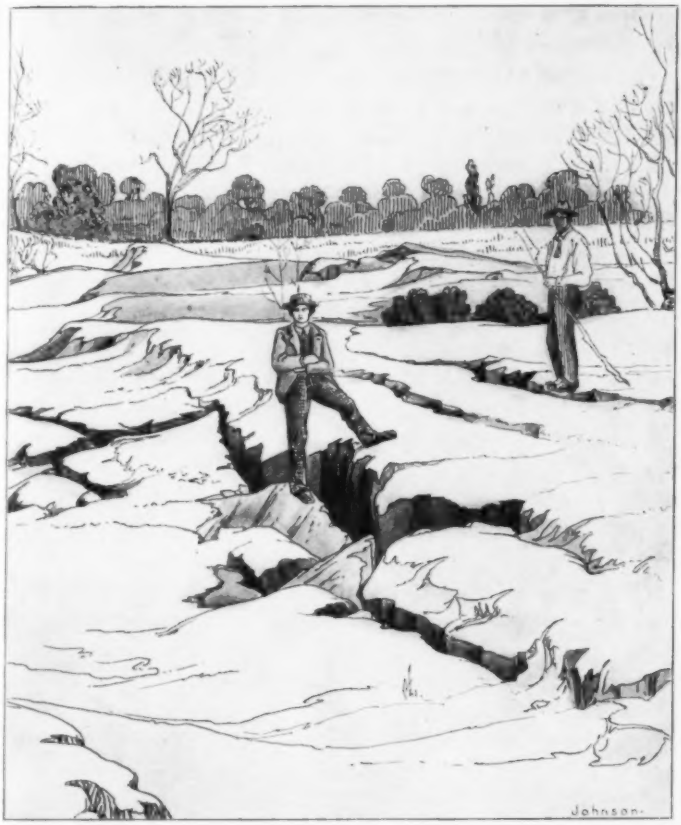


FIG. 4 —One of the fissures evidently formed by the earth cracking apart, owing to upheaval rather than by the earth being blown out. The piles of earth in the background of the picture correspond to x–x^1 of Fig. 1 and are at the south side of the main fissure, 1, 2 of Fig. 1.

When visited by the writer, four days after the explosion occurred, a little gas was escaping from many of the fissures, and this would burn for a short time when ignited.

It was reported by the citizens of the neighborhood that a fire had been burning in brushwood on a small island in the river about 150 yards above the main fissure previous to the explosion,

and it is probable that the escaping gas was ignited by this fire.

The accompanying figures show the nature of the fissures that were produced by the explosion.

Cause of the explosion.—The explosion was supposed at the time to have been caused by gas escaping below the casing from the wells at either St. Paul or Waldron, or at both places, and finding its way between the strata to the point where the explosion took place, at which point the strata were too weak to withstand the pressure.

Whether the gas did come from these wells, whether it came up from below through a crevice, or whether it was generated at no great depth in the strata, more or less directly below the area where the explosion occurred, is not known.

It is evident, however, that gas accumulated below an impervious layer until the pressure became sufficient to rend this impervious bed, when the explosion followed. The pressure required to do this cannot be known, because neither the depth nor strength of the confining strata is known.

It is obvious that gas, under a pressure of say two or three hundred pounds to the square inch, if confined by horizontal strata, sufficiently near the surface so that the weight of the overlying material would not equal the pressure of the gas, would tend to spread laterally between the strata, and to cause these to bend upwards. If the pressure should become great enough, the strata would finally break and the gas would escape, possibly with explosive violence. Such an explosion would not necessarily indicate that a large supply of gas was involved, for a small quantity would exert as great a pressure to the square foot as a larger one.

The area affected by the Ogden Cemetery explosion covered about ten acres; the pressure on this surface at 250 pounds[1] per square inch would have been 36,000 pounds to each square foot of surface.

Taking the weight of the shales and surface soil as 175

[1] The "rock pressure" of the gas in some portions of the Indiana field in 1890 was over 300 pounds to the square inch.

pounds to the cubic foot, this pressure would have equaled the weight of the overlying materials at a depth of 205 feet.

Assuming the pressure of the gas to have been 250 pounds to the square inch, then the strata which enclosed the gas prior to the explosion may have been anywhere between the surface and a depth of 205 feet.

FIG. 5.—View looking southwestward from the top of the bluff at 7, Fig. 1. Prior to the explosion the water of the stream flowed over the surface of the ground shown in the right foreground of the picture. (From a photograph.)

In closing, attention is directed to the fact that the locality in which the Ogden Cemetery explosion occurred is near the southwestern edge of the natural gas area of Indiana, and that

the Trenton limestone, the great gas producing formation, is about 850 feet below the surface at this point.[1]

J. F. NEWSOM.

STANFORD UNIVERSITY,
August 25, 1902.

[1] At Geneva, three and one-half miles southwest from Ogden Cemetery, Trenton rock (the gas producing bed of the region), was struck in a gas well at a depth of 832 feet. At Bickhart's mill, about two miles east of the cemetery, Trenton was struck at a depth of 864 feet, with gas at a pressure of 335 pounds to the square inch.

ETCHING OF QUARTZ IN THE INTERIOR OF CONGLOMERATES.[1]

General statement.—Those who have studied the Coal-measure and other highly siliceous conglomerates have frequently reported the occurrence of distinct evidences of etching of the quartz pebbles on certain of the exposed surfaces. The portion removed by the etching solutions may amount to as much as nine-tenths of the original pebbles, though one-third to one-half of their mass are more common amounts (Fig. 1). The pebbles affected exhibit strongly pitted and usually very rough surfaces on the exposed parts, while the portions remaining imbedded in the matrix retain unaltered their rounded water-worn characters. The position in which the etched pebbles have been most generally observed is upon the flat upper surfaces of ledges or upon similar surfaces of detached blocks, but instances have been noted, especially in the region about Olean, N. Y., where the etching is also strongly developed on the under sides of overhanging ledges. So far as known the only published discussion of the phenomena is by Dr. C. W. Hayes[2] who regards the etching as a superficial feature due to the action of azo-humic acid under ordinary atmospheric conditions.

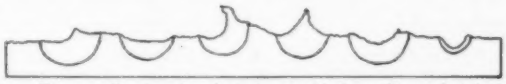


FIG. 1.—Section showing characteristic outlines of etched surfaces. Generalized from surface shown in Fig. 2, *A*.

Character of etching of conglomerate at Blossburg, Pa.—While examining the talus from an outcrop of Pottsville conglomerate at Blossburg, Tioga county, Pa., in 1901, the writer noted certain peculiarities which suggested that the quartz etching might be, in part at least, an internal rather than a superficial feature of the rock. The peculiarities first noted consisted of strongly

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] "Solution of Silica under Atmospheric Conditions," *Geol. Soc. Am., Bull.*, Vol. VIII, pp. 213–20.

etched pebbles (Fig. 2, *A*) upon the flat surface of a fragment of conglomerate which, judging from its shape, was a part of a much larger bowlder which had split apart along the etched surface. This seemed to indicate an internal etching along a bedding plane, but could not be regarded as conclusive. Further search, however, brought to light bowlders several feet in diameter in which etched bedding planes could be traced through the mass of the rock. Because of the thickness of the bowlders, specimens of the etched surfaces were difficult to obtain, but the character of the etching in a sandy portion of the rock is shown in the illustrations *B* and *C* of Fig. 2, which are from photographs of specimens taken from opposite sides of an etched plane extending through a bowlder of some size. Not only are the surfaces strongly pitted by the complete removal of a portion of the grains, but under a glass the individual grains, even those of the smallest size, exhibit distinct evidences of etching, either by distinct pittings, or by the general "ground glass appearance" of their surfaces.

Still further examination brought to light evidences of etching within quarried blocks at distances of five feet or more from the surfaces, but in these cases the etching was confined to the immediate vicinity of plant remains, now carbonized or changed to coal, and, so far as could be detected, was not connected with either etched or unetched bedding or joint planes. The etching, though distinct, was not of the pronounced type characterizing many of the bedding planes (Fig. 2, *A*), but was more of the character shown by the illustrations *B* and *C* of the same plate.[1]

The etching, so far as noted at Blossburg, was confined to the bedding planes or to the vicinity of the vegetable remains in the

[1] Specimens of quartz pebbles from the Carboniferous conglomerate of Ohio showing strong impressions of plant stems, were exhibited at the Cleveland meeting of the American Association, in 1853, by Professor Jehu Brainerd. These impressions, as urged by Professor J. S. Newberry, were probably due to the action of humic acids evolved during the decay of the vegetable matter, and appear to be of the same nature as the etching about the plant remains in the conglomerate at Blossburg. (See JEHU BRAINERD, *Origin of the Quartz Pebbles of the Sandstone Conglomerate and the Formation of Stratified Sand Rocks*, Cleveland, 1854, p. 16; and J. S. NEWBERRY; *Ohio Geol. Surv.*, Vol. II, Pt. I, 1874, p. 111.

mass of the rock. The portions of the conglomerate bowlders lying in the humus or exposed to the atmosphere, though sometimes presenting roughened surfaces suggesting etching, proved

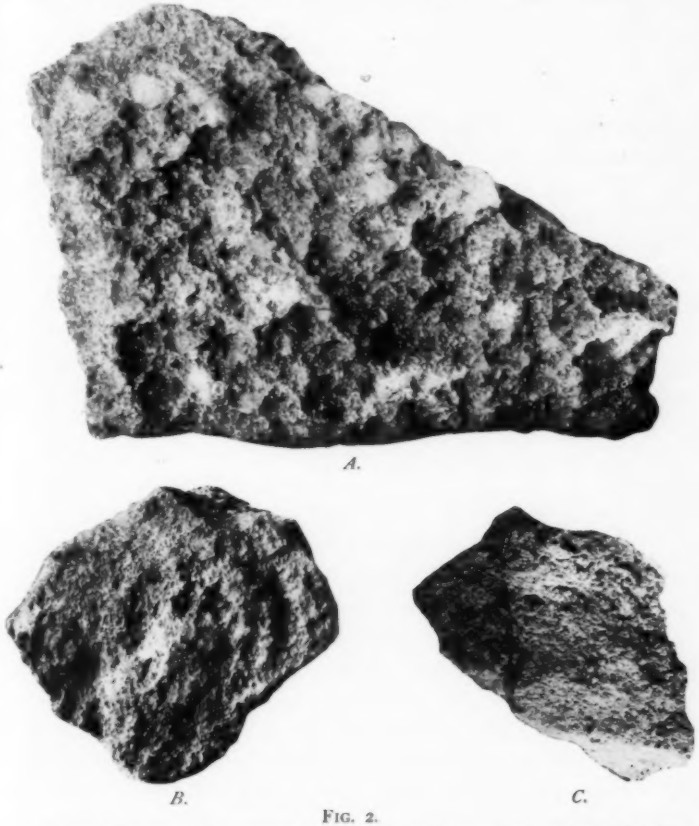


FIG. 2.

A. Etched surface of a bedding plane in Pottsville conglomerate from Blossburg, Tioga county, Pa.

B and *C.* Etched surfaces from opposite sides of bedding plane in a sandy portion of Pottsville conglomerate from Blossburg, Tioga county, Pa.

on examination to be unetched, the roughening being due to the separation of entire grains by the ordinary processes of disintegration. The deep channels and pot-like cavities observed in

the conglomerate at other points in Pennsylvania and described by Mr. Arthur Winslow[1] are of similar origin, the only work of solution apparently being the removal of the cement binding the grains together. The disintegration of the conglomerate into sand likewise appears to be unaccompanied by solution, except that of the cement.

Where the etched surfaces are fully exposed to the action of the weather, as on the upper surfaces of ledges, they are, so far as known, always bleached to a gray or white color, but where they are more or less protected, as on the under sides of overhanging ledges, they are almost invariably stained with iron. It is a well-known fact that the action of the humic acids is accompanied by a leaching of the iron constituent, or at least a conversion of the iron to the ferrous state, in which it is ordinarily inconspicuous. The oxidized condition of the overhanging surface would seem, therefore, to indicate that the etching, if due to the action of the organic acids mentioned, is not going on at the present time. The portions of the bowlders in contact with the humus of the soil, though not etched, are distinctly bleached.

Summary of evidence.—The evidences that the etching probably took place in the instances described in the interior of the conglomerate at some past time rather than at the surface under present conditions are as follows:

1. Etching has been noted about vegetable remains at distances of several feet from the nearest exposed surface, showing that the solution is not a superficial feature.

2. Bedding planes extending throughout bowlders of several feet in diameter are frequently etched throughout, indicating the penetration of the solvent to distances of at least a number of feet from the surfaces.

3. The continuations of horizontal etched surfaces, both on the upper and overhanging portions of ledges, frequently extend up to and disappear into the mass of the rock, the exposed

[1] "Peculiarities of the Weathering in the Pottsville Conglomerate," *Science*, Vol. III, pp. 12–14.

parts, in fact, apparently being portions of much larger surfaces, reaching well into the interior of the rock mass.

4. The etched surfaces, except those about the vegetable remains, appear generally, if not always, to be confined to principal or to cross-bedding planes, or at least to joints, or other planes of separation, such as might have afforded a passage for solutions through the rock. The general absence of etching on surfaces other than the types mentioned, especially on the exposed exteriors of the masses, strongly suggests that the etching was internal.

5. The lack of bleaching on many of the etched surfaces shows that the etching is not the result of organic solvents acting at the present time, and affords negative evidence in favor of internal solution.

Conditions during the etching.—On examining the etched surfaces, it is found that only the immediate exterior is affected, the pebbles and sand grains being pitted or planed down to a general surface, without there being, in most cases, the slightest evidence of solution of the cementing materials (Fig. 3). This evidence tends to show that the rocks were consolidated when the etching took place, and probably indicates rapid action of the etching solutions, for if the rocks were open and porous, as they would have been before consolidation, or if the solutions passed through them for considerable lengths of time, it seems almost certain that the solutions would have penetrated for some distance into the body of the rocks and would have produced an internal etching or disintegration of the portions adjoining the bedding or other planes along which the solutions passed. The existence of small open cavities about the vegetable remains is also probably to be regarded as evidence of the consolidated condition of the rock at the time the solution took place.

FIG. 3.—Diagrammatic section showing character of etched surfaces of conglomerate. (C. W. HAYES, *Geol. Soc. Am., Bull.*, Vol. VIII., p. 217.)

If the internal nature of the etching of the conglomerate is admitted, the question arises as to whether it occurred while the

latter was deeply buried or after it had become exposed at the surface through erosion. The extent of some of the etched surfaces, frequently amounting to several yards, or even rods, and the apparent continuation of these surfaces indefinitely into the rock, though affording no positive evidence, is at least suggestive of deep-seated conditions. The evidence afforded by the bowlders, however, appears to be more to the point, for it is difficult to conceive of conditions which would permit solutions to enter such bedding planes and to penetrate and etch the pebbles throughout their extent, while the external portions of the same bowlders, both where exposed to the atmosphere and to the humus of the soil, are entirely without evidences of etching.

Source and nature of the solvent.—The more sandy portions of the conglomerate at Blossburg contain considerable numbers of feldspathic grains, which, on weathering, it may be conceived, might have afforded alkaline solutions of sufficient strength to have produced an etching of the quartz. The fact, however, that other sandstones and conglomerates higher in feldspathic constituents in equally advanced stages of alteration, do not, in general, show any evidences of etching, makes it improbable, in the present instance, that the alkaline solutions were the active etching agents.

There appears to be no reasonable doubt that the solutions, which produced the etching about the fossil vegetable remains, were derived from the vegetable matter itself, in the process of the change from the original woody state to the present carbonized condition. Vegetable remains are abundant in many parts of the conglomerate, and must have furnished considerable quantities of organic acids. If, in fact, such was the source of the etching solutions, the latter, in order to reach the bedding planes or other passages, must have traversed the mass of the rock, probably through the agency of the force of capillarity. That the portions of the rock thus traversed are lacking in visible etching is probably due to the wide diffusion of the solutions and the relatively immense areas of the surfaces of the constituent grains.

The evidence, as far as it goes, would appear to favor the

view that the solvent had its origin in the vegetable matter of the rock itself, that it was concentrated along bedding planes or other passages in the rock, and that it was only where so concentrated that visible etching was produced. The etching is not, however, to be necessarily considered as confined to those parts of the rock abounding in vegetable remains, the solutions probably being conducted by the bedding or other planes to portions remote from the original source of the solvent.

Conclusions.—The observations have been insufficient to warrant broad generalizations, but the evidence, though not so decisive as might be desired, seems to favor, as far as the Blossburg locality is concerned, the conclusions given below. It is not probable, however, that they will hold for the occurrences at all localities.

1. The etching has not taken place under existing conditions. This is indicated by the unetched character of the portions of the rock exposed to the atmosphere or to the humus of the soil, and by the present oxidized condition of most the etched surfaces.

2. The etching is an internal feature, as is indicated by the etching about the plant remains, by the etched interiors of detached blocks, and by the extension of etched surfaces into the mass of the rock.

3. The etching took place after the rock was fully consolidated, as is shown by the fact that it is confined to the immediate walls of the bedding or other planes, the etching solutions failing to penetrate the rock or even to dissolve the cementing material except very locally.

4. The etching is believed to have taken place while the rock was moderately deeply buried, the depth, however, probably not exceeding 500 feet, this being a common limit of the circulation of fresh water below the general surface, as shown by the numerous oil and gas drillings in Pennsylvania.

5. The active solvent was probably an organic acid and was most likely derived from the vegetable remains within the rock itself.

MYRON L. FULLER.

U. S. GEOLOGICAL SURVEY.

THE OIL- AND GAS-PRODUCING ROCKS OF OHIO.[1]

THIS state began producing oil in 1860. From that period until 1885 the output was restricted to the eastern part of the state, and was derived entirely from rocks of Carboniferous age. The production during that time was relatively small, and of little importance in a commercial sense. In 1885 the vast repository in the Trenton limestone was discovered, and this at once gave the industry in the state great impetus. The yield was such that in 1895 it surpassed that of Pennsylvania and New York combined, and since that date the state has held the first rank. Gas first became an important fuel in Ohio in 1884, the year of the great discovery at Findlay. From 1888 to 1900, inclusive, the value of this product exceeded $28,000,000.

The rocks, particularly the lower ones, producing these vast supplies have been in part studied, especially by Orton,[2] but thus far no paper has been published which considered all the producing strata. It is the purpose of this article to enumerate these, to discuss briefly their composition and general characters, and to show their stratigraphical position.

THE ORDOVICIAN.

In Ohio the upper half only of this great division needs be considered. This is divided by Orton as follows:

3. Hudson River series - - -	300–750 feet
2. Utica shales - - - -	0–300
1. Trenton limestone - - - -	50

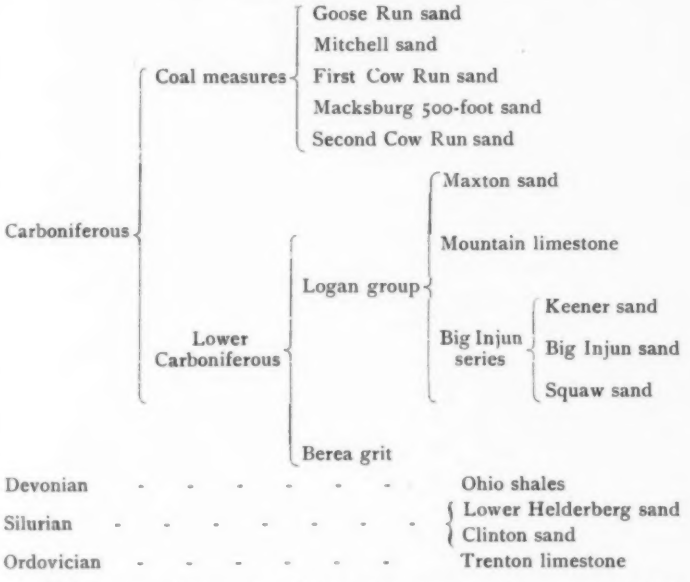
The upper two members contain both oil and gas, but rarely in commercial quantities. Occasionally high-pressure gas wells are found, but these soon give out. Nowhere in Ohio can either of these formations be regarded as a producer of natural gas. Occasionally in the northwestern corner of the state oil is found

[1] Published by permission of Edward Orton, Jr., state geologist.

[2] *Geological Survey of Ohio*, Vol. VI, and *First Annual Report* (1890).

in the upper members, and wells are known that have had a large initial production; but it is a general rule that such wells rapidly decrease, falling far short of their early promise.

THE PRINCIPAL DIVISIONS OF THE GEOLOGICAL SCALE IN OHIO, AND THE OIL- AND GAS-BEARING MEMBERS.



The Trenton limestone.—Quite the reverse, however, with the first member, known as the "Trenton limestone." Not only is this the most important source of oil in Ohio, but probably it is not excelled by any single formation in the world. It forms the floor, so to speak, of the entire state, being found wherever the drill penetrates to a sufficient depth. It is disputed whether or not the formation reaches the surface anywhere, but Dr. Orton considered the exposure near Point Pleasant in Clermont county as forming the top of the Trenton.[1]

The composition of the Trenton has been made the subject of careful investigation by Orton, who found that the oil- and

[1] *Geological Survey of Ohio*, Vol. VII, p. 4.

gas-bearing beds are magnesian. This is shown by the following analyses:

	$CaCO_3$	$MgCO_3$	Ins. Res.	Al and FeOx.
Findlay gas rock.....	53.50	43.05	1.70	1.25
Bowling Green gas rock....	51.78	36.80	4.89	....
Lima oil rock.....	55.90	38.85	.75	2.94

It was further found that in some places at least the magnesian character of the rock changes rapidly from the surface of the formation down. Thus an analysis of the rock lying 100 feet below the top of the Trenton at Bowling Green showed over 88 per cent. of $CaCO_3$ and less than 7 per cent. of $MgCO_3$; while, as shown above, the upper portion of the same formation has less than 52 per cent. of $CaCO_3$ and more than 36 per cent. of $MgCO_3$. The magnesian character is important, since it renders the rock porous, thus making it a suitable reservoir for the oil and gas. Outside of the producing territory in Ohio the Trenton loses its magnesian character, the $CaCO_3$ composing usually at least 75 per cent. of the formation.[1]

The rock is often highly fossiliferous, and occasionally the pieces brought up by the sand pump are little more than a cemented mass of shells, resembling in this respect the limestones of the Hudson River series. Dr. Orton referred the formation, as shown in the Findlay well, to the Galena, Trenton proper, and Birdseye divisions.[2] The total thickness of the Trenton in northwestern Ohio is unknown, but it exceeds 780 feet. In the southwestern part of the state it is 650 feet, as shown in a well drilled on the McGhee farm in Liberty township, Adams county. This thickness is similar to that reported in Kentucky.

The relation stratigraphically of the Trenton to the next important producer, the Clinton, is shown in the following records:

[1] *Ibid.*, Vol. VI, pp. 103, 104. [2] *Ibid.*, Vol. VI, p. 116.

WELL NO. 1, HAINES FARM, ROSEVILLE, SANDUSKY COUNTY

Drive pipe		30 feet
Niagara series,	Gray lime	140
	White lime	160
	Blue lime	20
	White slate, first break	2
	Brown lime, hard	21
	Light slate, second break	20
Clinton limestone		100
Medina shales (red)		80
Hudson River series (white shales)		427
Utica shale (brown)		252½
Trenton limestone at		1,252½

For comparison a record is given of a well drilled on the Rohr farm near Groveport, Franklin county, in the central part of the state:

Drift	136 feet
Ohio shales	167
Cornifereus limestone, top at	303
Niagara limestone, bottom at	980
Clinton shales	110
Clinton sand, shells only at	1,110
Trenton limestone at	2,146
Bottom of well (in Trenton)	2,675

THE SILURIAN.

The rocks of this age in Ohio are divided by Orton as follows:[1]

4. Lower Helderberg limestone	50–600 feet
3. Niagara limestone and shale	125–380
2. Clinton group	20–150
1. Medina shale	25–150

The Clinton.—Of these divisions the second and fourth only call for recognition in this article. Along its line of outcrop in southwestern Ohio the Clinton consists essentially of a highly crystalline limestone, rich in fossils, especially crinoid stems. Commonly it has a light color, the tint of which varies from place to place. The rock takes a good polish, and is sometimes called marble. Occasionally the formation contains lean hematite, and

[1] *Ibid.*, Vol. VII, pp. 4, 5.

one of the earliest blast furnaces in the state relied on this ore. In composition the rock is calcareous, and at one point becomes the purest rock of this type in the state.

Northward, under cover, the rock undergoes notable changes, the result being that it closely resembles the overlying Niagara. It is in the central portion of the state, however, that the greatest change is found. Instead of a well-marked limestone, there is found in its place shales of different colors and composition and a conspicuous sandstone; the latter the repository for the great reservoirs of gas in Fairfield, Hocking, Licking and Knox counties. In northern Vinton county a pool of oil also has lately been found in it, and one well has been secured in Perry county.

The relations of these beds to the overlying Niagara are shown in the following partial log of a well on the Bauer farm near Sugar Grove. Samples of drillings below the Niagara were taken by the writer.

Berea grit		top at	620 feet
		bottom at	645
Corniferous, Helderberg, and Niagara limestones		top at	1,430
		bottom at	2,132
Clinton	Shales, light chocolate-colored.	top at	2,132
	Little lime	bottom at	2,168
	Shales, green and chocolate-colored, the latter fossiliferous. Some lime	top at	2,168
		bottom at	2,199
	Shales, green and chocolate-colored. Much lime	top at	2,199
		bottom at	2,236
	Clinton sand at		2,236

Generally when the gas sand has been penetrated to a depth of from 10 to 15 feet the drill is stopped, and consequently data farther down are less abundant. In western Ohio the basal portion of the Niagara is commonly occupied by shales,[1] but northward and eastward this member contracts. In central Ohio it consists of shales and thin beds of limestone, and the bottom of these is regarded as the line of junction of the Niagara and the Clinton.

The following skeleton record of a well on the Spire farm near Sugar Grove shows the position of the Medina as well as the Clinton:

[1] *Ibid.*, pp. 11–13.

Drift	11 feet
Berea grit, bottom at	460
Corniferous, Helderberg, and Niagara limestones, top at	1,235
bottom at	1,921
Clinton sand, top at	2,025
bottom at	2,045
Medina (red shales) top at	2,055
Bottom of well at	2,075

This makes the red shales lying from 10 to 30 feet below the Clinton sand, the top of the Medina.

The Lower Helderberg.— Rocks of this age produce gas and oil in one locality, viz., near Jefferson, Ashtabula county. The succession of strata there is shown by the following record of Webb Well No. 1. All measurements were made with a steel line.

	Thickness of formation.	Total depth.
Drift	33 feet.	33 feet.
Ohio shales	1,671	1,704
Corniferous and Lower Helderberg limestones	288	1,992
Gas sand at		1,992

The sand, which is from 30 to 40 feet in thickness, is interbedded in the Lower Helderberg limestone. Similar conditions are found in Lucas and Wood counties, in the former of which the sand has been quarried for the manufacture of glass.[1] In the gas field under consideration the sand is moderately coarse, has a light color, and is highly fossiliferous. The gas is found in the top of the formation, and just below lies a large and threatening reservoir of salt water. A number of towns and villages are being supplied with fuel from this field. The oil wells are few in number and insignificant in production.

THE DEVONIAN.

The rocks of this age found in Ohio, have been classified by Orton[2] as follows:

3. Ohio shales	250–3,000 feet
2. Olentangy shale	25
3. Devonian limestone (Corniferous)	75

[1] *Ibid.*, p. 17. [2] *Ibid.*, pp. 4 and 18–26.

None of these formations produce oil, and the Ohio shales alone yield gas. The available supply of this, however is very small, and its use has been limited to domestic purposes. The principal counties have been those along the lake shore in the northeastern corner of the state. These shales, which underlie the eastern half of the state, are wedge-shaped, with the apex reaching from the lake to the Ohio. The cities, Columbus, Delaware, and Bucyrus, lie on or near this apex. Eastward the formation thickens rapidly and near Wellsville on the Ohio river has been penetrated to a depth of 2,600 feet without reaching the base. This feature has led to much confusion on the part of the driller, who has expected to find the interval between the Berea grit and the Devonian limestone, the same in the eastern part of the state that he did in the central.

The gas secured in these shales is not from any one horizon, but varies stratigraphically from place to place. The wells are all small. Very commonly the shales make a show of gas, but usually the yield is so light as to be commercially valueless. The aggregate amount contained, however, must be very large, and if it could be collected would form one of the most valuable supplies of fuel in the state.[1]

THE CARBONIFEROUS.

Classifying the formations of this great division, as has been customary, into the Lower Carboniferous, Coal-measures, and Permian, it is found that the oil- and gas-bearing rocks are restricted to the first two members. These will now be considered in order.

I. THE LOWER CARBONIFEROUS.

The Berea grit.—This is the most extensive sandstone of the state. Its area above and below drainage is about 15,000 square miles, or more than one-third of the area of the state. Its value is commensurate with its extent. "Its economic value above ground is great, but it is greater below. In its outcrop it is a source of the finest building-stone and the best grindstone grit

[1] For a full discussion of this subject see *Geological Survey of Ohio*, Vol. VI. pp. 410–42.

of the country, and when it dips beneath the surface it becomes the repository of invaluable supplies of petroleum, gas, and salt water."[1]

The composition and structure are very constant. The color is gray below drainage, but has a tinge of yellow above. The sand is of moderate fineness, and composed almost wholly of silica. Occasionally it contains carbonate of lime, probably as a cement, but this never constitutes more than a very small fraction of the formation. That found below the surface around the village Berea in Cuyahoga county is undistinguishable from that obtained at a depth of more than 2,000 feet in Washington county. Sometimes, though not usually, the formation divides, a bed of shale lying between two of sandstone; at other places the upper portion of the formation consists of sandstone and the lower of shales. In thickness the formation varies from 50 feet or more in the northern part of the state to a half dozen or less in the southeastern portion, and occasionally disappears entirely, its place being occupied by shales. The Berea grit is succeeded above by the Berea (Sunbury) and Cuyahoga shales, having usually an aggregate thickness of from 500 to 600 feet, and below by the Ohio shales, having a great and rapidly increasing thickness eastward. The most remarkable character of the formation, however, remains to be mentioned, viz., its persistence. From its outcrop it has been followed by the drill from county to county, and often from section to section, until the eastern and southeastern limit of the state is reached. It is as easily recognized below drainage as above, and this character makes it a stratigraphical landmark of great value to both driller and geologist. In many counties in the eastern part of the state, especially those fronting on the river, numerous efforts have been made to find a productive sand below the Berea, but in every case this effort has been unsuccessful. It may now be taken as having been demonstrated by the drill that when the Berea sand has been passed in this territory the last hope of oil or gas has gone.

While a trace of oil or gas has perhaps been found in every

[1] *Ibid.*, Vol. VII, p. 28.

county where the formation exists, the production in commercial quantities is limited to Lorain, Medina, Trumbull, Columbiana, Stark, Jefferson, Harrison, Belmont, Guernsey, Monroe, Noble, Vinton, Perry, Athens, Morgan, and Washington counties.

The Logan group.—The relative position of this group and the Berea is shown by the following skeleton record of a well on the Mead farm in the Elk Run Pool, Washington county.

Logan group	Salt sand	top at	1,200 feet.
		bottom at	1,280
	Maxton sand	top at	1,450
		bottom at	1,500
	Mountain limestone ("Big lime")	top at	1,510
		bottom at	1,545
	Big Injun series	top at	1,560
		bottom at	1,730
Berea grit		top at	2,124
		bottom at	2,138

This shows that the two formations are about 400 feet apart, and as has already been stated the interval is occupied by the Berea and Cuyahoga shales.

The Logan group, as classified by Orton, consists of three members — a conglomerate, sandstone, and shale — and has a maximum thickness of 350 feet.[1] Quite recently, however, Professor Prosser has considered the question, and he divides the group as follows:[2]

2. Logan formation = Logan sandstone and shales.
1. Black Hand Formation = Logan conglomerate.

Recent work by the drill demonstrates that the maximum thickness is twice that stated by Orton. The group is limited above by the Lower Carboniferous limestone, but this is rarely recognized in deep wells, and consequently the upper limit is usually uncertain. The first member of the group that is recognized by the driller is the Salt sand. The relation stratigraphically of this member to the Lower Carboniferous limestone is shown by the following record of a well on the Longshore farm in section 15 of Brush Creek township, Muskingum county. All measurements were made with a steel line.

[1] *Ibid.*, Vol. VII, pp. 4, 5, 32–5. [2] JOUR. GEOL., Vol. IX, pp. 205–31.

Putnam Hill limestone -	top at	20	feet.
	bottom at	23	
Lower Carboniferous limestone	top at	225	
	bottom at	265	
Salt sand - - -	top at	450	
	bottom at	485	
Berea shale - - -	top at	919	
	bottom at	952	
Berea grit - - -	top at	950	
	bottom at	980	
Bedford shales (brick red) -	top at	980	
	bottom at	1,010	
Ohio shales, top at - - - - -		1,010	

This shows that the Salt sand lies 185 feet below the Lower Carboniferous limestone. Combining this with the record of the Mead well previously given makes a total thickness for the Logan group of 715 feet. Probably in the extreme southeastern corner of the state the thickness is still greater.

Above drainage the group is well marked. Hills capped with sandstone or conglomerate stand out in bold relief, so that the limits of the formation are discernible from a distance. The conglomerate is the most conspicuous member of the group. It is essentially a quartz rock, the largest pebbles of which do not commonly exceed one-half of an inch in diameter. It is the best known bridge stone in the state. The sandstone member has usually a yellow or brown color, but sometimes this becomes strikingly variegated. It is extensively used for building purposes. The members of this group are much less constant in their physical characters than the Berea grit, and hence their identification is correspondingly more difficult.

Under cover the Logan group undergoes important changes, and the several formations are given different names from those at the surface. Thus, instead of the Logan conglomerate, sandstone, and shale, we have the Big Injun sand, Mountain limestone, Salt sand, etc. The correlation of the strata bearing these two sets of names is as follows. This is based on their stratigraphical succession and lithology. While the limits underground cannot be sharply drawn in most cases, they are perhaps as definite as those along the line of outcrop.

Logan shales	=shales (unnamed)
Logan sandstone	=Salt sand
Logan conglomerate	=Mountain limestone Big Injun series

The limestone just named, and which is known also as the "Big lime," has a maximum thickness in this state of 110 feet. It is a light-colored, hard, massive rock, free from oil and gas except along its margin, where the formation becomes broken and the layers of limestone are intercalated with sandstone. The formation is wedge-shaped with the apex to the northwest. It is limited to the eastern half of Washington and Monroe counties, and the southeastern corner of Belmont. To the west and north its place is occupied by shales and sandstones. The formation divides the Logan group into two unequal parts, and serves as a guide-post to the driller.

The Big Injun series.—This consists of the following members:

Slate - -	0– 20 feet
Keener sand - -	0– 60
Slate - -	0– 25
Big Injun sand	0–175
Slate - -	0– 10
Squaw sand -	0– 30

From this it is seen that the group varies greatly. Sometimes it is little more than one great mass of sandstone, while at other times it is broken into a series of alternating beds of slate and sandstone. The Keener sand occasionally lies immediately below the Mountain limestone, but more often is separated from that rock by a few feet of shales. It varies considerably in texture, but is usually coarse and open, sometimes conglomeritic. The sand was named from the Keener farm near Sistersville, West Virginia.[1] It is an important source of oil in Monroe and Washington counties. The sand is separated from the underlying Big Injun by a bed of slate. Sometimes the latter is wanting, and then the two sands run together and are conjointly called the Big Injun. The sand in question (Big Injun) is by far the thickest member of the series, but in other respects

[1] *West Virginia Geological Survey*, Vol. I, p. 357.

resembles the Keener. It is recognized in several counties in southeastern Ohio, but is a producer of oil or gas in commercial quantities in Monroe and Washington counties only. To the west and north the formation becomes too broken to be a repository for oil or gas. Below the Big Injun, and separated from it by a thin bed of shales, there is occasionally found another layer of sand known as the Squaw. It is decidedly patchy and never extends over large areas in this state. The best records of it are reported from Monroe county, but it is of little importance even there.

The Salt sand.—This is the highest of the sands of the Logan group. It has a gray color, is moderately coarse, and nearly always is charged with brine. Occasionally it contains a little oil and gas, but it cannot be recognized as a producer of either.

II. THE COAL-MEASURES.

While a large number of strata belonging to the Coal-measures have been or are now sources of oil, comparatively few of these have been important in a commercial sense. Generally the sands are local, and cannot be traced over an area of more than a fraction of a mile. Such sands usually have names, but because of their small area and production they will not be further noticed in this article. The most important sands of the Coal-measures are the following:

5. Goose Run sand.
4. Mitchell sand.
3. First Cow Run sand.
2. Macksburg 500-foot sand.
1. Second Cow Run sand.

The relative positions of sands 1 and 3 are shown by the following data taken from Centennial Well No. 6 at Cow Run:

	Thickness	Depth to top of formation
Pittsburg coal - - - -	1 foot	11 feet
First Cow Run sand - - -	47 feet	325
Second Cow Run sand - -	64	776

The stratigraphical relation of sands 2 and 3 is shown by the following record taken from Dunn Well No. 6, near Macksburg. The well head is six feet below the Meigs Creek coal.

	Thickness.	Depth to top of formation.
Ames limestone,	1 foot	285 feet
First Cow Run sand	5 feet	385
Cambridge limestone	4	411
Dunkard sand (300-foot)	95	530
Macksburg 500-foot sand	22	702

The Dunkard or 300-foot sand is quite generally regarded as the equivalent of the Mahoning. That this cannot be correct is shown by the following partial section of the Hocking Valley coal field.[1]

	Thickness.
Cambridge limestone	2–10 feet
Mahoning sandstone, upper division,	50
Brush Creek coal (No. 7a)	2½
Brush Creek limestone	4
Mahoning sandstone, lower division	15–25
Upper Freeport coal	0– 3
Upper Freeport: Clay, Shales, Limestone and sandstone	35
Middle Kittaning coal (No. 6)	5–13

This shows the Mahoning sandstone lying immediately below the Cambridge lime, but experience in the field demonstrates that the two are not ordinarily in contact. Measuring from the base of the lime rock to that of the Mahoning, an interval of 76 feet is found, while, according to the records in the Dunn well, the interval is 210 feet. A divergence of this sort cannot be explained by assuming that the section expands eastward, for a study of the relative positions of the Pittsburgh coal, the Ames and Cambridge limestones farther west with the same formations near Macksburg, shows no material change, and it is certainly unreasonable to assume that the formations just below the Cambridge limestone expand at anything like the rate that would be necessary to make the interval which this nomenclature requires. Further, naming the sand in question the Mahoning makes impossible a rational classification of the lower formations. The position of the sand with reference to the Cambridge lime is that of the Upper Freeport.

[1] *Geological Survey of Ohio*, Vol. V, p. 918.

The positions of sands 3 and 4 are shown by the record of Centennial Well No. 7, at Cow Run. The well head is at the horizon of the Meigs Creek coal.

	Thickness.	Depth to top of formation.
Pittsburg coal (No. 8) - -	1	116 feet
Mitchell sand - - -	25	205
Red shales ("Big Red") - -	80	235
First Cow Run sand - -	32	423

The relative positions of sands 4 and 5 are shown by the following taken from Reed Well No. 4, near Marietta:

Goose Run sand -	top at 300 feet bottom at 331
Mitchell sand - -	top at 525 bottom at 546

The Second Cow Run sand.—This is one of the least important members of the group now under consideration. It has been a small producer at Cow Run in Washington county for more than thirty years, but rarely has been found beyond that locality. It is reported, however, quite frequently, for the driller gives this name to almost any sand lying from 100 to 500 feet below the first Cow Run sand. As may be seen from the records given the interval between the two is 400 feet. It lies 760 feet below the Pittsburg coal, and is the thickest member of the group, sometimes exceeding 60 feet. Occasionally the formation is divided by few feet of slate, in which case the oil lies in the lower part. The sand possesses no qualities that serve to distinguish it from the higher members.

The sand belongs near the base of the Coal-measures. The partial record of the Rice well, given below, shows it to be the first sand above the Salt sand, the two being separated by 79 feet of shales, the latter probably the equivalent of the shales of the Logan group. This, with the thickness of the formation, and the fact that it is sometimes divided by a few feet of shales, makes quite certain its identification as the Massillon sandstone.

The Macksburg 500-foot sand.—This is important at Macksburg and vicinity only. It lies 670 feet below the Meigs Creek coal

and about 580 feet below the Pittsburg, as is shown in the following partial log of George Rice Well No. 18, at Macksburg.[1]

	Thickness.	To top of formation.
Meigs Creek coal	5 feet	10 feet
First Cow Run sand	35	343
Dunkard sand (300-foot)	78	554
500-foot sand	17	685
Sand, pebbly (800-foot)	51	775
Slate	79	826
Salt sand	190	905

This sand commonly ranges from 10 to 30 feet in thickness. It is usually quite coarse, but does not become a conglomerate. Like the First Cow Run sand, it does not form a continuous stratum, but is decidedly patchy. Stratigraphically considered, the formation belongs near the top of the Conglomerate Coal-measures, and its position with reference to the Cambridge lime and Dunkard sand strongly indicates that it is the Tionesta sandstone.

The Second Cow Run and the Macksburg 500-foot sand have been regarded by many as equivalent. As has already been suggested by Professor White, however, this cannot be the case.[2] Examination of the record of the Rice well shows that the interval between the First Cow Run and 500-foot sands is only 307 feet, while, as already stated, the interval should be 400 feet. Measuring from the Meigs Creek coal, equally conclusive figures are secured. Thus the Second Cow Run sand lies 840 feet below the Meigs Creek coal, while the interval between this seam and the 500-foot sand is only 670 feet. The sand at Macksburg known as the 800-foot is probably the equivalent of the Second Cow Run.

The First Cow Run sand.—This is the most important and best-known sand of the group. As is shown in the record of the Dunn well, its position is 100 feet below the Ames limestone. In western Morgan county, near the outcrop of the sand, the interval ranges from 70 feet to 100. The Ames limestone there lies 170 feet below the Pittsburg coal. The identification of the

[1] *West Virginia Geol. Sur.*, Vol. I, p. 298.

[2] *West Virginia Geological Survey*, Vol. I, p. 299.

sand is made more certain by the fact that the Cambridge limestone lies immediately below or is separated from the sand by a thin bed of shales. Unfortunately these limestones are not recognized in Monroe and the eastern part of Washington counties, and hence the sand in question often cannot be identified there with certainty. In such localities any shallow sand, especially if it makes a show of oil or gas, is known as the Cow Run. The relation of the sand to the two limestones places it about 100 feet above the base of the Conemaugh formation.

If the Berea grit be taken as the type of a persistent stratum of sandstone, the First Cow Run sand may properly be selected as the representative of the opposite type. It is the most patchy of the oil or gas rocks of Ohio. The maximum thickness of the formation may be taken at 50 feet, but even a short distance from this the stratum may become very thin or actually disappear entirely. The texture varies much, and where productive is sometimes conglomeritic. Pebbles three-fourths of an inch in diameter have been found, and those one-fourth of an inch are common. The pebbles consist of quartz, but small grains of other minerals are found. From this type the formation changes to a hard compact sandstone.

The sand is an important source of oil in Morgan and Washington counties. It seems to have been first struck at Macksburg in 1860, where it is known as the 140-foot sand; this being the depth at which the sand was found in the valley at that place. In 1861 the sand was found at Cow Run and has there been a producer ever since. It is seen that the latter name has not the claim of priority, but it is so much more widely used that it is here retained.

The Mitchell sand.—This is the source of a small oil field a few miles east of Marietta. The sand is comparable in thickness with the First Cow Run, but in texture is less conglomeritic. As has been shown, it lies about 90 feet below the Pittsburg coal, or 200 feet above the First Cow Run sand. Its place is near the summit of the Conemaugh formation. Wells in this sand commonly begin with a relatively large production, but decrease very rapidly.

The Goose Run sand.—The formation known by this name has supplied a score or more small wells near Marietta. The sand is patchy, and the life of the wells very short. In fact, the rock is of little value, and is recognized here simply to make the record complete stratigraphically. Lying nearly 200 feet above the Mitchell, the sand belongs 100 feet above the Pittsburg coal, or, in other words, near the middle of the Monongahela formation.

The following table shows the great divisions of the Coal-measures of Ohio, and also the approximate positions, at least, in these of the several sands just discussed:

Dunkard formation, or Upper Barren Coal-measures, 500 feet.	No oil or gas rocks.
Monongahela Formation, or Upper Productive Coal-measures, 200 feet.	Goose Run Sand. 100 feet. Pittsburg or No. 8 coal.
Conemaugh formation, or Lower Barren Coal-measures, 500 feet.	90 feet. Mitchell sand. 200 feet. First Cow Run sand. Cambridge limestone. Mahoning sandstone.
Allegheny Formation, or Lower Productive Coal-measures, 250 feet.	Upper Freeport or No. 7 coal. Dunkard or 300-foot sand = ? Freeport sandstone. 50 feet.
Conglomerate Coal-measures, 250 feet.	Macksburg 500-foot sand = ? Tionesta sandstone. 70 feet. Second Cow Run sand = Massillon sandstone. Sharon or No. 1 Coal.

J. A. BOWNOCKER.

COLUMBUS,
October 10, 1902.

THE ARAPAHOE GLACIER IN 1902.[1]

In the front range of the Rocky Mountains of Colorado are several remnants of glaciers. One of these, the Arapahoe glacier,[2] has an area at present of about one-half square mile. It lies on the eastern slope of the continental divide, twenty-one miles due west from the city of Boulder. It is inclosed by nearly vertical walls five to seven hundred feet in height, forming a deep cirque opening to the east. The valley leading eastward is that of a branch of North Boulder Creek. This valley has been occupied by a glacier to a distance of at least eight miles to the east. The bottom of the valley for four miles eastward from the present glacier is occupied by a series of lakes resulting from the glacial action and the intervening topography is marked by roche moutonees (Fig. 1). The front of the glacier has retreated up this valley to its present position, and its length has been thereby reduced from nine miles to one mile.

The features of this glacier at the close of the summer of 1902 have a peculiar interest. The snowfall for the past three winters has been deficient, and the melting in the ensuing summers has been excessive. The results of these climatic circumstances appear in a great contraction of the ice-covered area, an unusual exposure of fresh moraines and, what is still more important, an almost complete absence of snow below the névé. This last condition is responsible for many fine exposures revealing the stratification of the ice, and for the complete uncovering of crevasses, some of which stand open as much as ten feet.

Moraines.—The bottom of the valley is far from being a single trough, and the glacier is therefore by no means a single

[1] The observations on which this account is based were made in the last week of August. The photographs were taken by Judge Junius Henderson, of Boulder, Colo. The map is constructed from a survey made by Hugh F. Watts, of Boulder, Colo.

[2] For a general description of this glacier, its position, dimensions, shape, and evidences of its true glacial character, see paper by Willis T. Lee, this Journal, Vol. VIII, p. 647.

ice stream. In its more vigorous days, when it filled the valley for some miles and was some hundreds of feet deeper than at present, the inequalities of its bed must have been unable to control the ice movement to any great extent, and therefore failed to subdivide the glacier into a system of branching tribu-

FIG. 1.—Looking east, down the valley, from a point one-half mile below the present terminus of the glacier. The shelf seen at the left is in the main rock terrace. The lower and narrower valley suggests uplift and considerable erosion before the glacier was developed.

taries. It must then have appeared essentially as a single ice stream. Indeed, its appearance, as viewed from the neighboring mountains two years ago,[1] seems to have suggested but two branches, separated by a moraine so low that a few extra yards of depth would have rendered the whole a unit at the surface. The valley bottom below the present terminus is barred with crescent-shaped terminal moraines which mark the termini of

[1] WILLIS T. LEE, *loc. cit.*

the small glaciers into which the larger ice mass became divided in its dying stages. Other crescentic moraines are now just becoming exposed at the present border of the ice, the horns of the crescents being in the positions of medial moraines which were formed on the valley bottom between tributary glaciers, and are now for the first time being exposed by the wasting of

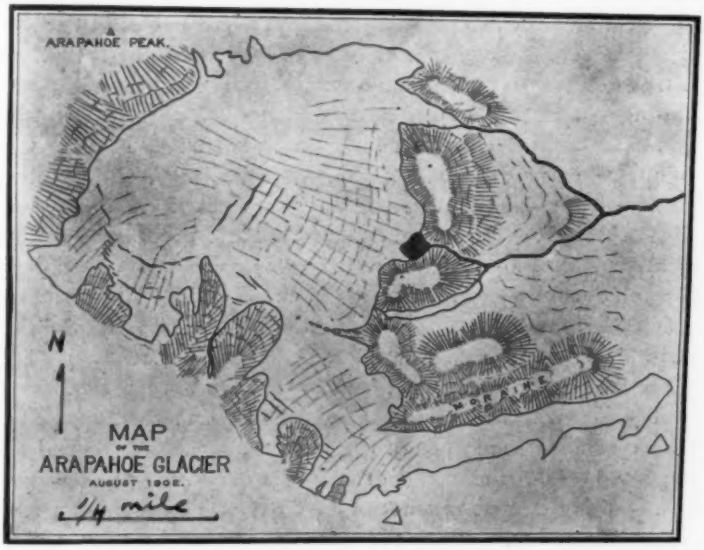


FIG. 2.

the ice. Several of these medial lines are distinctly terminal in their relations to the ice on either side, as shown by the fact that the movements of the ice are not in the direction of such lines, but normal to their trend from both sides. (One such is well shown on the map, Fig. 2.)

The moraines whose positions indicate that they have been for a long time exposed are composed, not of rounded bowlders, but of large fragments from among which all smaller stones have been removed. This statement is made of those near the present limit of the ice, and therefore formed since the

glacier became very short. Those situated some miles down the valley contain many rounded bowlders, for the obvious reason that many of these have traveled far. Between the moraines of great angular fragments and the ice, are newer ridges whose constitution is in striking contrast with that of the outer ridges. These newer deposits contain fragments of the same order of size as those contained in the older ridges, but intermixed with them are stones of all smaller sizes. In these ridges, often capping the several fragments or lying in masses at the very summit, are quantities of mingled mud and gravel so fresh that they bear almost no evidence of having been washed by the rains of a single season. They resemble nothing so much as the fresh dump from a great steam shovel. On the north side of the glacier such a ridge rises from forty to fifty feet above the present level of the ice, showing that the surface of the glacier has wasted by at least that amount since the ridge was formed. The unwashed character of its summit makes it difficult to admit that more than a single season has passed since its first exposure to subaërial weathering. This necessitates the conclusion that the glacier has wasted at least forty or fifty feet during the past summer.

The recent contraction of the glacier is further evidenced by the exposure of ice in one of the fresh morainic ridges now well separated from the body of the glacier (Fig. 3). Superficially this ridge differs not at all from any other moraine of recent formation. Except for the fortunate section which reveals its core, it would appear to be built of a framework of huge fragments, from among which the finer materials have been but partly removed by surface erosion. The section, apparently due to stream erosion, exposes a surface of perhaps twenty or thirty square yards of ice. The position of the stratification planes, dipping toward the head of the glacier, agrees with the supposition that these ice masses may still be in place, having been covered and protected by the abundant débris at the ice front. A second ridge of similar character, only partly separated from the glacier and several hundred feet within the first ridge, is plainly the result of the present summer's melting. The front of the ice was early in the season completely covered with

rock débris. This covering formed such a protection that the outer rim of the glacier wasted more slowly than the ice immediately in the rear. A trough has therefore begun, which in another season like the one just past, may grow to such an extent as to leave the inner ridge completely detached from the glacier.

FIG. 3.—Terminal moraine; the dark bands are ice. The rocks between the dark bands probably overlie ice. The stratification of the ice is transverse to the bands seen here.

The third steep ice front behind the second trough is already becoming covered with débris. A series of years of deficient snowfall or excessive melting, or both, might in this way produce a series of concentric ridges having ice cores, whose subsequent melting would leave a topography very much more choppy than that which would result from a series of ordinary recessional moraines. It is suggested that a part of the very confused morainic area several miles east of Silver Lake may thus be connected with the wasting of the glacier at an excessive rate.

Crevasses.—A second great advantage from the recent deficiency of snowfall and the excess of melting was found in the complete uncovering of crevasses. No part of the glacieris free

FIG. 4.—Crevasse, open about 10 feet.

from cracks, but near the middle a greater steepness of the bed gives rise to crevassing on a large scale (Figs. 4 and 5). The slope of the ice surface for some distance at this place was

measured at twenty-four degrees, which is greater than the slope at any other place excluding the névé and the immediate margin of the glacier. Many of the crevasses in this zone are forty rods long, and some stand open as much as ten feet. They are spaced at intervals of a few yards. The blocks thus formed appear to have been tilted forward. This is inferred from the fact that the

FIG. 5.—General view looking south over crevasses to the névé.

brink on the lee side of each crevasse is higher than that on the opposite or stoss side, and the surface of each block has a steeper slope than that of the ice as a whole in this vicinity. Lines dropped into these crevasses did not reach depths greater than fifty feet, but apparently water is running at much greater depths. The appearance of the ice in these crevasses is clear and bluish, with occasional bands which are stained as if with dust. In the same zone are some small cracks, limited in length to seven or eight feet, which stand open about two inches at the center.

Near the margin of the ice a system of longitudinal crevasses is made quite prominent by the control which these exercise over

the surface drainage. They reach apparently no great depths. Many of them, which are several feet in depth and contain running water, are open less than half an inch at the top. Much of

FIG. 6.—The Bergschrund, open about 15 feet. The columns at the right are ice; above them is snow.

the surface drainage follows these narrow crevasses. That they are primarily due to fracture and not to erosion is evident from their absolute straightness for long distances.

A most striking feature of this glacier is the prominent *Berg-*

schrund, or gaping crevasse, at the line which may be taken as the limit of the névé and the beginning of the glacier proper (Fig. 6). The very steep slope of the névé, its whiteness, and the solitariness of this great crack make it strikingly prominent from any point from which the glacier is visible. It is almost continuous around the cirque and stands open at many places as much as ten or fifteen feet. A partial descent into this opening revealed the fact that it traverses from ten to twenty feet of snow at the surface, below which is a colonnade of great icicles lining a chasm at least fifty feet deep. Independent of these icicles the walls of the chasm below the ten or twenty feet of snow, seem to be of the same blue ice which is seen in the crevasses at the center of the glacier.

In the examination of crevasses the excessive melting of the past summer proved a most fortunate circumstance. Probably every crevasse down to the most minute was uncovered. The real significance of this appeared after a snowfall of not more than two inches on August 28. On the following day many crevasses, having widths approximating ten inches, were found completely covered by crusts of snow. It seemed evident from this that a snowfall of a very few inches would easily obscure crevasses in which a man might be lost.

The complete absence of surface snow was of great advantage in observing the stratification of the ice. Dark lines which were nearly horizontal and continuous for long distances were plainly visible for some miles. These mark the outcrops of ice strata. The alternate strata are of clear ice, while the intervening ones have a more spongy texture, the constituent beds being for the most part not thicker than two inches and usually less than one inch. The wasting of layers of varying hardness produces small cliffs and platforms analogus to those observed in canyons cut in stratified rock. The fine débris accumulates along the lines of these outcrops and forms the dark lines which are visible for great distances. The dip of stratification planes near the margin of the ice is well seen in the canyons of surface streams and is uniformly toward the direction from which the ice comes (Fig. 7). Dips of thirty degrees or more

are common a hundred yards from the edge and the steepness increases as the margin is approached. Englacial drift disposed in planes was found at only one point and that was in the buried ice. The material incorporated here contained nothing coarser than sand. Planes showing discoloration, as if by dust accumulated on the surface, are not uncommon. In the larger crevasses

FIG. 7.—Stream channel showing stratification of the ice—100 yards from front.

these are sometimes very prominent in contrast with the clear bluish ice.

The drainage of the glacier has no special peculiarity, and in this lies its chief interest, because it aids in classifying this ice field with well-developed alpine glaciers. Streams are guided largely by crevasses and frequently drop suddenly into the body of the glacier. Pits are not uncommon; one of these, whose opening at the surface was less than ten square inches, was found to be three feet deep.

Where the ice is snow-covered and on the smaller segments which do not take on the nature of perfect glacier ice, there often results from the surface drainage a peculiar hummocky surface. The process by which these hummocks or knobs come into existence is somewhat indirect. The water draining from a very steep surface of uncompacted névé, produces at first a

FIG. 8.—Lake within the present terminal moraine. The prominent lines in the ice at the left are shearing planes.

system of small parallel channels, which may be a yard or two apart. The water in these channels percolates to some extent, and in freezing produces under the channel a rib which is harder and more ice-like than the snow between channels. Differential melting next leaves what was once a channel exposed as a ridge. This ridge has at no time an even crest, and soon comes to appear as a line of small icy hummocks regularly spaced at intervals of a few feet. The isolated patches of névé attending the Arapahoe glacier, which are just too small to take on com-

plete glacial character, often show this knobby surface to a remarkable degree.

The water issuing from below the glacier is characteristically milky. Small pools are found whose bottoms cannot be seen at depths greater than four inches. The turbid water escaping from below is soon mixed with the clear drainage from the surface, and the turbidity is thereby reduced; but the first few lakes of the long chain in the valley below are notably turbid.

There are no records of the extent of this glacier in former years. It is viewed from the rim of the cirque by occasional visitors to Arapahoe peak, but visits to the glacier itself have been rare. A few photographs taken from the surrounding heights in former years would indicate that the loss of forty or fifty feet in depth during the season just passed is not all to be credited to the permanent wasting of the glacier. That amount has plainly disappeared from the surface since last winter; this conclusion seems necessary from the presence of absolutely fresh mud on the top of the moraine which rises to that height above the present ice surface. Former photographs, however, also show this same ridge rising above the ice, though by a less amount than at the present time. As stated above, the past two or three years have been favorable to wasting. As the glacier is now accurately mapped and largely photographed, a few more years may yield the interesting determination whether the present climate of this locality in the Rocky Mountains is capable of supporting a permanent glacier or whether the recently observed shrinkage is a part of its final disappearance.

A second consideration of theoretical significance is connected with the rock terraces several hundred feet high on the sides of the valley below the present glacier (Fig. 1). These plainly indicate an uplift. It is equally plain that the glaciation was not the result of the uplift. The valley cut below these terraces is several hundred feet deep and five hundred to one thousand feet wide. If the glaciation as well as the valley *trenching* resulted from this uplift, then the small stream must have cut out the above-mentioncd valley in the time required for the ice to accumulate after the climate became suited to glaciers.

This assumption is evidently absurd, and it becomes necessary to assume that a considerable interval elapsed between the uplift and the advent of a glacial climate. The supposition may still be made that the glaciation followed close upon another and later uplift. The significance of the observations in this particular terraced valley is not in excluding hypotheses of later uplifts, but in making clear the time relations between the uplift here exemplified and the coming on of the glacier.

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THE FRANCEVILLE (EL PASO COUNTY, COLORADO) METEORITE.

THIS meteorite was bought by Professor F. W. Cragin, of Colorado College, Colorado Springs, Colo., from Mr. David Anderson and wife of Colorado Springs. It was found by Mr. Anderson, as nearly as he can remember, in 1890, about one and one-half miles southwest of the home ranch of Skinner and Ashley, which is east of Franceville. According to Mr. Anderson, it was totally above ground, and there were no signs of any other meteorites.

From the time it was found until purchased by Professor Cragin it had been kept in the home of Mrs. Anderson in Colorado Springs, half-forgotten. It was purchased from Professor Cragin by Ward's Natural Science Establishment, Rochester, New York, in August, 1902. From its external form it is one of the most interesting of the many meteorites that have been in the possession of that firm.

It is a decidedly flattened rhombic pyramid with a somewhat sharp ridge extending around the center of the mass on the four rhombic sides. The dimensions of the mass in these directions are 21×23^{cm} with a thickness of 11.5^{cm}. On one side of this central axis the pyramid projects 6^{cm}; on the opposite side, 5.5^{cm}, as seen in Fig. 2.

The decidedly octahedral form of this iron seems unquestionably due to its separation along natural cleavage planes from a much larger mass; but it is surprising that the form should not have been much more distorted by the erosion due to friction in passing through the atmosphere.

The whole iron is more or less mottled, ranging in color from a reddish-brown to a brownish-black. It is entirely covered with pittings on all sides. Those on what may properly be termed the upper side (Fig. 1) are much more distinct, owing to their size and depth, than elsewhere. Just below the medium ridge on one end there is an unusually large pitting, some 10^{cm}

long and 2 cm deep. There are two or three small, but much deeper, finger-like pittings from which troilite has undoubtedly been weathered out.

Two small corners of the mass have been broken off and have the appearance of very old breaks, as the surfaces are entirely oxidized. These surfaces show markedly distinct octa-

FIG. 1.—Upper side, showing pittings. (Two-fifths actual size.)

hedral cleavage. Probably not more than thirty grams have been taken from it since it reached *terra firma*. Two small protuberances, one 2 cm, the other 1 cm in diameter, were sawed off, and the faces polished and etched. One of these is shown in Fig. 1, the other in Fig. 2. Otherwise the mass was entire until sawed into sections.

Upon slicing the mass but one troilite nodule of any size was found. This occurred on one end-piece and the adjoining slice, and was 14 mm in diameter, with two small patches of nickel-

iferous iron in its center. The slices show fractures more or less extending across their surfaces along the natural cleavage faces which are the edges of the kamacite plates, and in some instances the rhombic form produced by the Widmanstätten figures, as is the case in the San Angelo meteorite,[1] are strongly outlined by these fissures.

Upon etching the iron the Widmanstätten figures are readily brought out by acids. These are particularly sharp and clear,

FIG. 2.—Showing pyramidal form. (Two-fifths actual size.)

and of large size, as shown in Fig. 3. The kamacite plates average from 1 to 1.5 mm in diameter, with an occasional one of 2 mm. They are unusual in the fact that they extend in an unbroken line in many instances from 90 to 120 mm in length. The taenite occurs in minute films between the kamacite plates.

The plessite patches are comparatively small for an iron of such coarse crystallization. Some of these patches show no structure when etched, except a slightly pitted surface, while others are prominently made up of alternate layers of kamacite and taenite, producing sharply the so-called Laphamite lines.

Schreibersite is not visible on the etched surfaces microscopically, not even surrounding the troilite nodules, as is usually the case.

[1] *American Journal of Science*, Ser. 3, Vol. V, pp. 269-72.

Mr. John M. Davison, to whom was given 23.9 grams for analysis, reports:

The specific gravity of this siderite is 7.87. A proximate analysis gave:

Soluble in hydrochloric acid, kamacite and taenite,		99.16 per cent.
Combined carbon, not determined.		.....
Undissolved in hydrochloric acid	schreibersite	0.837
	graphite and silicates (trace)	.003
	platinum (from 23.9 grams)	trace
		100.

The analysis of kamacite and taenite together gave Fe. 91.92 per cent.
Ni. 8.13

100.05 per cent.

The weight of this most interesting siderite is forty-one pounds and six and one-half ounces, or 18.3 kilograms.

Colorado has not been prolific in supplying meteorites to the scientific world. As far as noted, there have been but five, including the present iron, all of which are siderites, viz.:

Russel Gulch, Gilpin county	found 1863
Bear Creek, near Denver	found 1866
Jefferson, thirty miles from Denver	fell June, 1867
Franceville, El Paso county	found 1890
Mount Ouray, Chaffee county	found 1894

One of these, the "Jefferson (No. 81, Shepard Collection), thirty miles from Denver, Colo.," listed as having fallen in June, 1867, I can find no account of outside of the descriptive catalogue of the meteorite collection in the United States National Museum, January, 1902. It seems apparent that a mistake has been made in labeling this specimen, and it must be dropped as a distinct fall for the following reasons:

The Bear Creek meteorite has been noted in most catalogues as having been found in Denver *county*, Colo., which is also a mistake, as Colorado has no county by this name. The Bear Creek meteorite was first mentioned by Shepard[1] as found upon the eastern slope of the Sierra Madre range of the Rocky Mountains, and Henry[2] notes it as found in a deep gulch near

[1] *American Journal of Science*, Ser. 2, Vol. XLII, pp. 250, 251.

[2] *Ibid.*, pp. 286, 287.

Bear Creek, about twenty-five or thirty miles from Denver. Smith[3] in describing this meteorite gave it the name of Bear Creek. As Denver is on the boundary line between Arapahoe and Jefferson counties, and as there is a Bear Creek extending clear across Jefferson county from west to east, emptying into the Platte, according to Henry's description, the locality of the

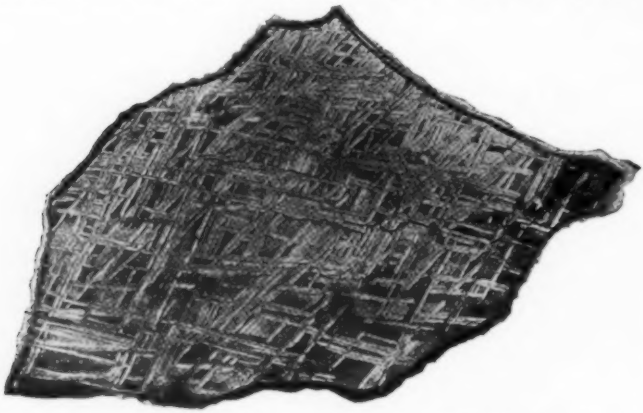

FIG. 3.—Section showing Widmanstätten figures. (Three-fifths actual size.)

Bear Creek meteorite must lie in the west central part of Jefferson county.

Therefore it seems likely that the iron noted in the Shepard Collection as "Jefferson, thirty miles from Denver," is in reality a portion of the Bear Creek meteorite labeled "Jefferson," meaning Jefferson county, and that the date of fall, June, 1867, is an error; particularly so, as the Bear Creek is described by Henry[2] as being "shattered on one end," so that small pieces could be readily detached. "Denver county" has evidently been substituted for "Denver city" in many of the meteorite lists, as no county is given in any of the early reports of the Bear Creek meteorite. Moreover, the Sierra Madre range is west of Denver, and the Bear Creek meteorite is described as having been found on its *eastern slope*, which in all probability

[3] *Ibid.*, Vol. XLIII, pp. 66, 67.

would bring it in Jefferson county. So it would seem best that "Jefferson" should be discarded entirely as a distinct fall and be called "Bear Creek," and that "Denver county" in all meteorite lists should read "*Denver city*." Thus we reduce the Colorado meteorites to four distinct falls.

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Studies for Students.

THE MAPPING OF THE CRYSTALLINE SCHISTS.[1]

II. BASAL ASSUMPTIONS.

Introduction.

Deformation under compressive stresses either by flow or by rupture.
Deformation zones of the lithosphere.
Mechanics of deformation by flow.
Mechanics of deformation by rupture.
Systems of faults.
Direct genetic relations of joint systems to systems of normal faults.
Criteria for recognizing a system of folds.
Criteria for recognizing a combined system of joints and faults.
Key areas for determining manner of deformation of a region.
Nature of evidence for establishing a fault.
Nature of evidence for establishing a system of faults.
Method of mapping an area deformed by a system of folds in conjunction with a system of faults.

INTRODUCTION.

In an earlier paper bearing this general title[2] the writer has discussed the methods of mapping the crystalline schists, and taken occasion to emphasize the necessity for a larger use of outcrop maps for all complexly deformed areas. It was also advocated that many peculiarities of rock exposures besides those ordinarily observed be examined and recorded, and their significance be sought in the final interpretation — the drawing of boundaries and the coloring of the map. In the present paper it is proposed to go somewhat deeper into the subject, and to discuss the basal and perhaps unconscious assumptions of the geologist in the making of his map.

If the writer's contention is upheld, it will be shown that methods of mapping have not kept pace with the advance of

[1] Published with the permission of the director of the United States Geological Survey.

[2] Jour. Geol., Vol. X, 1902, pp. 780–92.

the science of geology, and that, whereas the mechanics of crustal deformation, as now understood, and observation alike, take account of two distinct methods of rock deformation, geological mappers seem generally to have regarded but one as possessing much significance. The subject is an intricate one and one which does not readily lend itself to absolute demonstration, but in another place concrete examples will be chosen and described in some detail to show that the subject is a much larger one than is ordinarily understood.

DEFORMATION UNDER COMPRESSIVE STRESSES EITHER BY FLOW OR BY RUPTURE.

The stresses within the earth's crust which bring about sufficiently important deformation to affect the tectonic structure of an area may be assumed to be vertical compression due to the weight of superincumbent material, and lateral compression due to crustal shortening from whatever cause,[1] but in the last analysis a result of gravitation. Tensile stresses are locally produced when rocks assume new attitudes under compressive stress, but their importance as a direct cause of deformation over considerable areas is probably subordinate and largely limited to the effect of temperature change in surface masses of igneous rock, and hence may largely be dismissed from consideration in the present discussion.

The generally accepted classification of displacements resulting from earth stresses has been thus expressed by Suess:[2]

> The visible displacements[3] in the earth's superstructure of rock are the result of movements which proceed from the diminution of volume of our

[1] VAN HISE, "Estimates and Causes of Crustal Shortening," JOUR. GEOL., Vol. VI (1898), pp. 10–64, also, "Earth Movements," *Trans. Wis. Acad. Sci., etc.*, Vol. XI (1898), pp. 465–516.

[2] SUESS, *Das Antlitz der Erde*, 1885, Vol. I, p. 143. See also, MARGÉRIE ET HEIM, *Les dislocations de l'écorce terrestre*, Zürich, 1888, p. 8.

[3] The double meaning of the German and French words *Dislocation* and *dislocation* is especially unfortunate. In continental usage "dislocation" is employed in its more general sense for "displacement" (as for example, in the title of Margérie and Heim's work), and quite generally also in a special sense for "disjointing," or equivalent to "faulting." American usage is, I believe, wholly restricted to the word applied in the latter sense.

planet. Strains brought about by this process indicate an inclination to differentiate themselves into tangential and radial strains, thereby inducing horizontal (that is, compressive and folding), and vertical (that is, depressional) movements. Displacements have therefore been separated into two principal groups, by one of which have been produced more or less horizontal, by the other more or less vertical changes of position of portions of the crust.

Under compressive stresses rocks may suffer deformation in one or both of two ways: by flow, when under sufficient load; and by rupture, when the load is insufficient to cause flow.

DEFORMATION ZONES OF THE LITHOSPHERE.

It has been shown that at a depth of 10,000 meters, more or less, even the strongest rocks must find relief from stress by flow, and hence below that depth there must be a zone which, as respects its manner of deformation, may be called the zone of flow.[1] At very moderate depths relief from stress will be obtained by rupture, and this uppermost belt is therefore denominated the zone of fracture. Since, however, the depth at which rocks will flow is dependent primarily upon their crushing strength, there will be an intermediate zone or belt within which deformation will take place partly by rupture and partly by flow (zone of combined fracture and flow). There are many other conditions—such as amount of contained water, elevation of isogeotherms, etc.—which modify the depths of the zone of flow, but they need not be taken up here.

It is clear from these considerations that rocks may be deformed at one period by fracture (when under light loads), and at another time by flow (when below a depth of 10,000 meters, more or less). During a general elevation of a region deformation by flow within a given rock mass, will in general precede that by fracture, and the structures which arise from fracture will be superimposed upon those developed by flow. During a considerable subsidence of a province structures due to flow will be superimposed upon fracture structures and either wholly or partially efface them. The presence in the same

[1] VAN HISE, "Principles of North American Pre-Cambrian Geology," *Sixteenth Ann. Rept U. S. Geol. Survey*, Part I (1896), pp. 589–94.

rocks of well-developed flow structures and well-marked fracture structures independent as regards their direction of the flow structures, is strong evidence that the deformation by fracture was subsequent to that by flow. Moreover, in the very nature of the problem it is to be assumed that a fracture structure will in most cases be superimposed upon a flow structure, owing to the fact that degradational forces, as they continuously remove the upper layers of the lithosphere, gradually relieve the load upon the deeply buried rocks, until these are at last exposed to our view. This, however, is not the only reason why we should assume a fracture structure to be the later when found in conjunction with a flow structure, for fracture structures are quickly effaced by flow, whereas flow structures, though disturbed and distorted, are not obliterated by fracture structures.

THE MECHANICS OF DEFORMATION BY FLOW.

The mechanics of this problem is a large subject fully treated elsewhere[1] and may well be largely omitted from this discussion. Deformation by flow produces flexuring or folding of the initially horizontally bedded rocks. The position and the shape of the individual flexures will be determined by many factors: as, the position of old shore lines with their planes of weakness, and the initial dip of the beds resting upon them; the position of masses of igneous material (which by refusing to yield as readily as the bedded rock may elevate a portion of the latter above the zone of flow and cause rupture by thrust at the planes of maximum mashing); the position of earlier planes of rupture or foliation, etc. Flexuring is thus the method by which the heavily loaded rocks accommodate themselves to lateral compression, and results in a crustal shortening and thickening. In every fold there is a local compression normal to the beds in the limbs of the fold, and a local tension in the same relative direction in the arches, the tendency of which is to cause a local transfer of rock mate-

[1] WILLIS, "Mechanics of Appalachian Structure," *Thirteenth Annual Report U. S. Geol. Survey*, Part II, 1891–2, pp. 211–282. VAN HISE, *loc. cit.*, pp. 589–668; see also SUESS, *Antlitz der Erde*, Vol. I, pp. 142–189; MARGÉRIE ET HEIM, *loc. cit.*, 49–87.

rial from the limbs to the arches, the limbs becoming thinner and the arches thicker by this process. Foliation planes, or planes of easy separation, are also produced, which in moderately compressed folds make small angles with the axial plane of the folds,[1] but in closely compressed folds they are approximately parallel to that plane.

MECHANICS OF DEFORMATION BY RUPTURE.

The problem of deformation by lateral compression of a crustal block has been treated from a mathematical standpoint by Becker,[2] his discussion assuming the section of crust to be an elastic solid.

This block may be regarded, then, as subjected to stresses from which it acquires the properties of an anisotropic medium in which the greatest and the least axes of the strain ellipsoid lie in the horizontal plane, owing to the fact that gravity opposes an elongation of the particles in the vertical direction. The effect of such stress is to produce a system of vertical planes of dislocation which in a mass of infinite resistance (perfect elasticity) would make 45° with the direction of pressure, but otherwise (if more or less plastic) the angle would be less. With pressures rapidly applied it is believed that rocks behave like highly elastic bodies. The best evidences that such is the case seem to be furnished by the almost universal observation that the most prominent joint planes are nearly vertical (except in subsequently tilted rocks) and so generally nearly perpendicular to one another;[3] and by the experiments of Crosby,[4] who found that a system strained to a point far below that of rupture (near which plasticity becomes for the first time an important factor) is relieved from its stress by dislocation through shock communicated to the system (for example, by an earthquake). In the

[1] See this JOURNAL, Vol. X, p. 787.

[2] GEO. F. BECKER, "Finite Homogeneous Strain, Flow, and Rupture of Rocks," *Bull. Geol. Soc. Am.*, Vol. IV (1893), p. 50; see also VAN HISE, *loc. cit.*, p. 672.

[3] A. DAUBRÉE, *Études synthetiques de géologie expérimentale*, Part I (Paris, 1879), pp. 300, 301; see also BECKER, *loc. cit.*, p. 73.

[4] W. O. CROSBY, "The Origin of Parallel and Intersecting Joints," *Am. Geol.*, Vol. XII (1893), pp. 368–75.

opinion of the writer, these considerations render invalid many of the data collected from test pieces in laboratories. Elsewhere the writer has developed this subject more extensively.[1] It has there been pointed out that the production of a system of vertical and perpendicular joint planes may be, and probably would be, but the first step in the process of relieving by rupture the stresses within a crustal block. By the formation of prismatic joints the potential energy of the system is lowered and a readjustment of the stresses brought about. Furthermore, a tendency is set up favoring local depression, for the reason that rocks in the zone of fracture support their load by their rigidity, and this element of rigidity has been much reduced through the system of dislocations. The crustal block rests upon the rocks in the zone of flow, which are in a condition of potential fluidity, or potential viscosity. The differences of composition and density within the zone of flow, combined with the varying perfection of the joint planes within the zone of fracture (which may be due to lack of homogeneity and perhaps to other causes), furnish conditions for a most irregular and unequal depression of the component blocks produced by the dislocation. On the basis of experiments and observation alike it is believed that the type of tectonic structure produced, before planed down by erosive agencies, may be well illustrated by that of a mosaic, the backing of which has been removed and the component blocks so disturbed as to stand at different altitudes, but with similar axes parallel.

A resumption, or, what is more likely, a continuation, of strong compression of an area in the same horizontal plane, or a second shock communicated to it, would doubtless produce a result of a somewhat different character from the first. The resultant of the lateral compressive stress is by reason of the ready-formed joint-planes resolved in directions parallel and perpendicular to them, the former producing a shear along the planes themselves, and the latter a shear along the diagonals of the blocks of the primary system. Torsional stresses are also set up so as to produce fracturing at the edges of the prismatic

[1] *Twenty-first Annual Report U. S. Geol. Survey*, Part III, pp. 124–33.

blocks. If the direction of the new compression made a large angle with the direction of the first, the directions of the new planes of dislocation would be difficult to determine, and torsion would be at a maximum. If, however, its direction corresponded closely to the first, as is most likely if it occurred in the same general period of disturbances affecting the area, the later planes of dislocation would in their directions bear a simple relation to the earlier. New depression of the area would quite likely follow the new dislocation.

Gilbert has shown that within an area which is undergoing depression along fault planes it is likely that earthquakes will follow one another in succession, owing to the fact that orographic blocks are supported in part by the friction along their vertical walls, and that starting friction is greater than sliding friction.[1] The momentum acquired by the slipping block is effective in reducing temporarily the energy of the system, and time is required for its recovery.

To summarize the mechanics of crustal deformation by rupture, it may be assumed that its result would probably be to produce vertical polygonal prismatic blocks bounded by joint and fault planes in a number (large or small) of parallel series intersecting one another, and that these blocks would stand at relatively different altitudes.

SYSTEMS OF FAULTS.

Continental European geologists have quite generally recognized the importance of systems of normal faults in bringing about important deformations, and have described such systems in many widely separated areas. This may, in fact, be said to constitute the most marked line of cleavage between the structural geological investigations of Europe and of America. The trend of European investigation in this regard was early given by Leopold v. Buch in Germany and Élie de Beaumont in France. The latter correctly located along the Rhine valley[2] parallel

[1] GILBERT, "A Theory of the Earthquakes of the Great Basin, with a Practical Illustration," *Am. Journ. Sci.* (3), Vol. XXVII, 1884, pp. 49–53.

[2] DUFRENOY ET ÉLIE DE BEAUMONT, *Explication de la carte géologique de la France*, Vol. I, p. 398.

lines of faults, and, following the theory of the time, supposed the mountain masses upon either side of the Rhine valley to have been forced up above their former level so as to produce a deep channel. That there are many parallel faults which follow the direction of the valley walls of the Rhine has been abundantly proven by later investigations.[1] Today the presence of numerous dislocations in parallel and often intersecting series[2] has been recognized in many European areas extending from the steppes of southern Russia upon the east, to the Pyrenees upon the west, to describe which there have been brought into use a considerable number of special terms. Some of these terms have no equivalent English expresssion, and such as have are, in some cases, unnecessarily long. Among the foreign terms are: Ger. *Bruchfeld*, Fr. *champs des fractures* (area of dislocations); Ger. *Bruchnetz*, Fr. *réseaux régulier des failles* (fault net-work); Ger. *Senkungsfeld* (sunken area); Ger. *Horst*, Fr. *horst* or *mole* (elevated area left between two or more sunken areas); Ger. *Scholle* (orographic block); Ger. *Graben* (long and narrow sunken block); Ger. *Brücke* (long and narrow elevated block); Ger. *Thurm* (relatively high block of nearly equal basal dimensions); Ger. *Kessel* (relatively low block of nearly equal basal dimensions); etc.

It has been especially the work of Suess to correlate the many scattered observations and in the first volume of his monumental work upon *Face of the Earth*[3] to show how the lineaments of the continent are lines of normal faulting, between which great crustal blocks have been depressed by different amounts. In America the description of what I have called the

[1] DAUBRÉE, *Description géologique et minéralogique du departement du bas-rhin* (Strasbourg, 1852), pp. 384–406; BENECKE and COHEN, *Geognostische Beschreibung der Umgegend von Heidelberg* (Strasbourg, 1881), pp. 595 ff.; AUSFELD *Geologische Skizze der Gegend von Rheinfelden, Mitth. d. Aárg. naturf. Gesell.*, Vol. III (1882), pp. 83–102; etc.

[2] In German usage the term *System* is generally employed to cover any grouping whether of parallel or of intersecting faults. The author has described under the term "*series of faults*" a group of parallel faults, restricting the use of the larger term "*system of faults*" to the network composed of parallel series. *Twenty-first Ann. Report U. S. Geol. Survey*, Part III, pp. 98 ff.

[3] *Antlitz der Erde*, Prag and Leipzig, 1885.

mosaic type of infaulted structure seems to have been restricted to papers upon the Great Basin of the West and upon areas of Newark rocks along the Atlantic border, in both of which provinces only the simplest types of folding are observable. It is highly probable that joints and "minor faults" have been elsewhere frequently observed but thought to have throws so small as to be negligible, the cumulative effects of the small displacements along numerous near-lying planes being overlooked. Faults have too frequently been regarded as isolated phenomena. Within the crystalline areas isolated normal faults have sometimes been supposed to stand in some relation to folds, and because evidence of individual faults is within such areas most difficult to secure, faults have been the last resort of mappers in securing harmony between areal relations and basal hypotheses. The tendency to use faults "to get out of tight places" has probably been in direct ratio to the inadequacy of the hypotheses assumed, and it is, therefore, not strange that faults have been and still are in much disfavor among the most competent and conscientious of American geologists. There are, however, as the writer believes, methods of showing the connection of a *system of faults* with the deformation of an area, through the peculiarities of its joint system, topography, hydrography, outcrop distribution, etc.

It will be the object of this paper to point out especially the methods of recognizing fault systems when in conjunction with systems of folds, because in the manner of deformation of an area is involved the most fundamental assumptions of geological mapping. The view that important deformation may be brought about within a folded area of the crystalline schists by a system of normal faults, has hardly been discussed by American geologists, the system of folds being invariably present and supposed to be the only important manner of deformation exhibited.

The impression should not be gained that in the mind of the writer the relative importance of the two methods of deformation is correctly set forth by the space here devoted to each. Deformation by folding is comparatively well understood and

exploited in the literature,[1] whereas, as pointed out, the consideration of deformations by a system of fractures is, at least for American areas of the crystalline schists, a new departure in geological mapping.

DIRECT GENETIC RELATIONS OF JOINT SYSTEMS TO SYSTEMS OF NORMAL FAULTS.

As early as 1879 Daubrée brought out clearly the relation of normal faults to planes of jointing. As in the case of so many other important discoveries, however, little weight seems to have been attached to the results by contemporary geologists, and it is doubtful if one geologist in ten now records with care the direction of joint planes. His conclusions the eminent French geologist states as follows:

1. The constancy over large areas of the orientation of certain systems of joints has been already confirmed by Sedgwick, de la Beche, John Phillips, and later by other geologists. Further, it has been recognized in Cornwall that the joints maintain their direction in passing from the granite into the schist or *killas* to traverse which they penetrate.

..... This permanence of orientation of the joints ..... makes them approach faults, of whose mechanical origin there is no doubt.

It is further known that in many countries joints may be seen passing by various intermediaries into faults properly so called.

2. The direction of joints in Yorkshire has been the subject of a great number of observations of another eminent geologist, John Phillips,[2] who has collected them into a rose of directions: it results that two directions predominate greatly over the others and that the two directions are perpendicular to each other.

3. [Referring to the deformation and distortion of fossils in the vicinity of joints.] ..... It is therefore an important result to have arrived at a consideration of joints as the effect of rupture the same as faults, which differ above all by their dimensions.

4. [Referring to the pebbles of conglomerate which have been observed to be neatly cut through by joint planes.] ..... A powerful cutting or shearing action has operated in the formation of joints.

To summarize, the characteristic feature which manifests itself in the innumerable fissures of the earth's crust is a parallelism which reproduces itself in the large and in the small fractures—in the fault as in the joint.[3]

[1] See WILLIS, *loc cit.*; MARGÉRIE ET HEIM, *op. cit.*; VAN HISE, *loc. cit.*

[2] PHILLIPS, *Illustrations of Yorkshire*, Vol. II, 1836.

[3] DAUBRÉE, *Géologie Expérimentale* (Paris, 1879), pp. 304–6.

A joint becomes a normal fault so soon as displacement occurs along its walls, and the essential difference, therefore, between normal faults and joints may be said to lie in this condition. An area of the earth's crust which has been deformed by jointing under compressive stress is thereby made especially liable to vertical changes of level, because its rigidity, and therefore its competency to uphold its load, has been reduced. Depression of the area, as a whole (and perhaps elevation of certain portions of it), will take place along the joint planes already formed. There is thus, probably, in all cases at least an infinitesimal displacement along the joint walls, and thus no sharp line can be drawn separating joints from faults.

Brögger, in his work upon the Langesund-Skien region of southern Norway, says of the joint and fault system:[1]

"The dislocations, that is to say, the faults, have in fact cut the landscape through and through, and not alone parallel to one system of lines, but first chiefly parallel to two principal systems, and then also parallel to other less prevalent directions. . . . .

If we consider how thickly the rocks are penetrated by very small faults, it follows, in fact, that a portion of the crust cut up in this fashion is built up like separate rectangular blocks of masonry.

The study in much detail of the circumscribed area of the Pomperaug valley in Connecticut and its vicinity[2] brought out facts quite independent of, but altogether harmonious with those discovered by Brögger in Norway.

In the Connecticut region it was shown that a system of nearly vertical faults falls into a number of intersecting series of parallel dislocations, of which four are quite prevalent, and that the directions of the series bear relations to one another, for which an explanation may be found in the mechanics of jointing under compression. A relation was also disclosed between the directions of the faults and the sizes of the included orographic blocks. It was further observed that the system of faults is parallel to and grades into the system of joints, and like it is

[1] W. C. Brögger, "Spaltenverwerfungen in der Gegend Langesund-Skien," *Nyt Magasin for Naturvidenskaberne*, Vol. XXVIII (1884), p. 401.

[2] Hobbs, "The Newark System of the Pomperaug Valley, Connecticut." *Twenty-first Annual Report U. S. Geol. Survey*, Part III (1901), pp. 1–160.

spaced with an approach to uniformity. As regards the larger displacements of the area, it was found that they seldom occur wholly along one plane, but are distributed over a zone of parallel and near-lying planes — the throw is distributed.

The faults of the less common series run along the diagonals of the larger composite blocks, and are believed to owe their formation to the downthrow of these blocks, and not to the original relief of the area from compression.

CRITERIA FOR RECOGNIZING A SYSTEM OF FOLDS.

While not necessarily present in all areas of disturbed rocks, it is fair to assume that in all areas of the crystalline schists in which bedded rocks are found, folds will be recognizable. The possibility of unraveling their relations to one another within a system will depend upon the intricacy of the structure, the frequency of the exposures, the freshness of the rock, the perfection of a combined joint and fault system, etc.

In general it may be said that flow structures and those produced by fracture are in contrast, the former exhibiting warped (curving) surfaces, and the latter plane surfaces. The courses of the fold structures across the map are, therefore, curved lines, whereas the latter course over the map in straight lines, or in zigzags made up of rectilinear elements. The courses of fault structures upon the map are little disturbed by the relief of the topography in proportion to their inclination — hade, being absolutely unaffected by topography when the hade is 90°. The nature of known formation boundaries upon the map, and that of other structures is thus one of the most important considerations in the determination of the kind of deformation to which the area has been subjected. When alternations of pitch of folds are not present, folded rocks present also rectilinear boundaries, but this consideration loses importance in most areas of intricate geological structure, because evidences of pitch can generally be made out. Change of pitch has been described as characteristic of few areas, because, as already explained, it has until comparatively recently seldom been looked for.

Other indications of the presence of flexures within a given

area are observed at the individual exposures. In areas of folded rocks minor curvings of bedding planes are usually exhibited, and generally in great perfection. Changes in the strike and the dip of the beds are, when large or numerous exposures are found, observed to be, in general, gradual rather than abrupt; and, if abrupt, search will reveal intermediate values for the dip, or the strike, or both, as the case may be. Foliation planes are characteristic of, and connected with, folding, but not with faulting.

CRITERIA FOR RECOGNIZING A SYSTEM OF FAULTS.

The characteristics of a jointed and normally faulted area of the earth's crust have been touched upon in the last section. With abundant outcrops this structure may be disclosed upon the areal map by the generally rectilinear or zigzag boundaries of formations. If not, some indication may be afforded by the prevalence of straight lines and sharp bends in the topography, particularly if the lines fall into parallel and intersecting series. Such a relief may not be apparent without careful examination of the map, for the reason that the particular combination of directions is not known, and it may yet be quite striking when once discovered. Again, the drainage lines may compose a network which in direction conforms both to that of the topographic lines, and that of the formation boundaries. The prominent joints observed at the individual exposures, it may be supposed, will also be in conformity with the directions of the geologic and topographic lines above enumerated. This has never been better expressed than in the classic work of Professor Th. Kjerulf upon the geology of southern and central Norway, which concludes with these words:

> Thus the great systems of fissures which cut up the surface produce the primary lines in the aspect of the surface of Norway. The mysterious network of these lines is stamped in indelible characters; this may indeed remain a long time unnoticed; if, however, it has once been seen, it will never again escape observation. Like a moss-grown inscription upon a plate of marble, it is there and may be recognized. Here all embodied representations of plateaus, of tilted plains, and of every sort of erosion have not prevailed to hide the writing or to withdraw it from observation. Push these all aside and

the eye again sees the runic characters, and it depends only upon this, that they all be correctly understood in the future.[1]

The observation of these striking lineaments of the surface, however, unless they be of great perfection, hardly furnishes an adequate demonstration that an important deformation by faulting has occurred. The proof of this must rest upon the discovery of a considerable number of individual faults whose directions relegate them to a system of parallel and intersecting series. The methods by which individual faults may be recognized will be outlined in the sequel.

KEY AREAS FOR DETERMINING THE MANNER OF DEFORMATION OF A REGION.

In geological mapping it is almost an unwritten law that geological sequences must be established at points where formations appear in their larger masses at the surface, it being assumed that structural relations are in such cases the simpler. Areas which show a considerable number of formations brought closely together in small masses at the surface are looked upon with suspicion as areas of local and "minor" faulting, or as containing intercalated beds of unusual types due to purely local conditions of sedimentation. Whichever of these views is assumed, the areas are likely to receive but small attention; first, because the problem of their structure is difficult to unravel and not regarded as affecting the larger questions of the region; and, second, because if once unraveled, the scale of the map would not allow of its representation. Such areas are, therefore, most frequently represented upon the map in the color of the formation which is believed to compose their greater part.

However unsuited these intricate areas may be supposed to be for establishing the order of succession of geological formations, they are nevertheless, it is believed, in many cases the keys (and perhaps the only ones) to unlock the secret of the manner of deformation which has affected the area as a whole. Complicated indeed, they often require only patience and industry for their unraveling, whereas the larger masses by their

[1] *Op. cit.*, p. 334.

very simplicity of areal distribution allow of several hypotheses, any one of which would adequately explain them.

NATURE OF EVIDENCE FOR ESTABLISHING A FAULT.

The several ways in which individual faults may be discovered the writer has elsewhere recited.[1] Some of them are alone sufficient as proof, while others must be regarded as offering incomplete evidence to be weighed in connection with additional observations. As modified for the problem before us these methods will now be considered. Many of them could apply equally to thrusting or to normal faulting, but observation of fault hade will generally be sufficient to determine which in a given case is present.

1. *The observation of beds formed at different times in juxtaposition along a plane transverse to their bedding.*—With conformable formations such an observation may be regarded as absolute proof of a fault, and is, in fact, one concerning which there is no disagreement among geologists. It is only rarely, however, that such a contact will be found exposed, and hence the method serves but seldom.

2. *Offsetting of formations in outcrop.*—Almost equally reliable as a method for determining a fault is the offsetting of formations in outcrop. If in following the mutual boundaries of two formations, the formations are found abruptly thrown to the right or left and continued either along the old or in a new direction, it is only necessary to show that the core of a pitching fold has not conditioned the break of continuity to prove the presence of a cross fault. When several such faults occur in series with throw in the same sense, either the apparent course of the boundary as a whole is given a different rectilinear direction, or a crescentic outline is conditioned. The crescentic ridges which are so prominent a feature of the Connecticut valley are produced in this way. The three ways in which such ridges may be produced by normal faulting have been elsewhere pointed out.[2]

3. *Offsetting of outcrops as definite topographic features.*—With rocks which are resistant to the erosive agencies, or where fault-

[1] *Twenty-first Annual Report, U. S. Geol. Survey*, Part III, pp. 85–93.

[2] HOBBS, *loc. cit.*, pp. 95–8.

ing has been accomplished in a not too early geological time, orographic blocks may cause a distinct offsetting of elevations upon the general surface and display an arrangement in zigzags or *en échelon*, which it is difficult to explain upon any other basis than that of normal faulting. Fig. 1 shows by the outline of the wooded area the serrated border of schist outcrops due to this cause. In Fig. 2 are exhibited four distinct orographic blocks of limestone arranged *en échelon* and owing their position above the general level to a skeleton work of silica which has fitted them to withstand the gnawing effect of erosion.

4. *Dikes.*—It has long been recognized that dikes of igneous or aqueo-igneous rock, and veins whose walls are plane surfaces, represent the positions of either joint or fault fissures which have been subsequently filled. Especially in the Harz mountains of northern Germany has this method of finding the position of old planes of dislocation been successfully employed.

5. *Abrupt changes of strike and dip not indicated in folds.*—An essential characteristic of every folded area is that gradational values can be found to correspond to all important changes of strike or dip, owing to the fact that folds appear in curves in nearly all of their sections (with undulating crests and trough lines in all sections, otherwise in all sections except those parallel to crest and trough lines). With excessively sharp pitching folds, changes of strike and dip by small amounts may be as abrupt as though caused by faults, but search will generally reveal at the apex, in the one case the core of the fold, and in the other the evidences of rupture, although it is quite possible that both will be found together.

6. *Discovery of fault breccia.*—*Reibungs* or fault breccia is very generally found where fault planes of considerable throw are actually uncovered. It is also often found in other places and especially in pits and shafts where access to the wall rock is not possible. Even in these cases, however, it furnishes valuable evidence that faulting has occurred. The formations which are in contact along the fault plane are likely to be indicated by the angular fragments of the breccia, which are usually cemented together by calcareous or siliceous material.

FIG. 1.—Normal faults indicated by offsets of areas of outcrop in the topographic features. View looking north-northwest along the western flank of the Laurel Lake Ridge, Lee, Mass.

FIG. 1.—Normal faults indicated by offsets of areas of outcrop in the topographic features. View looking north-northwest along the western flank of the Laurel Lake Ridge, Lee, Mass.

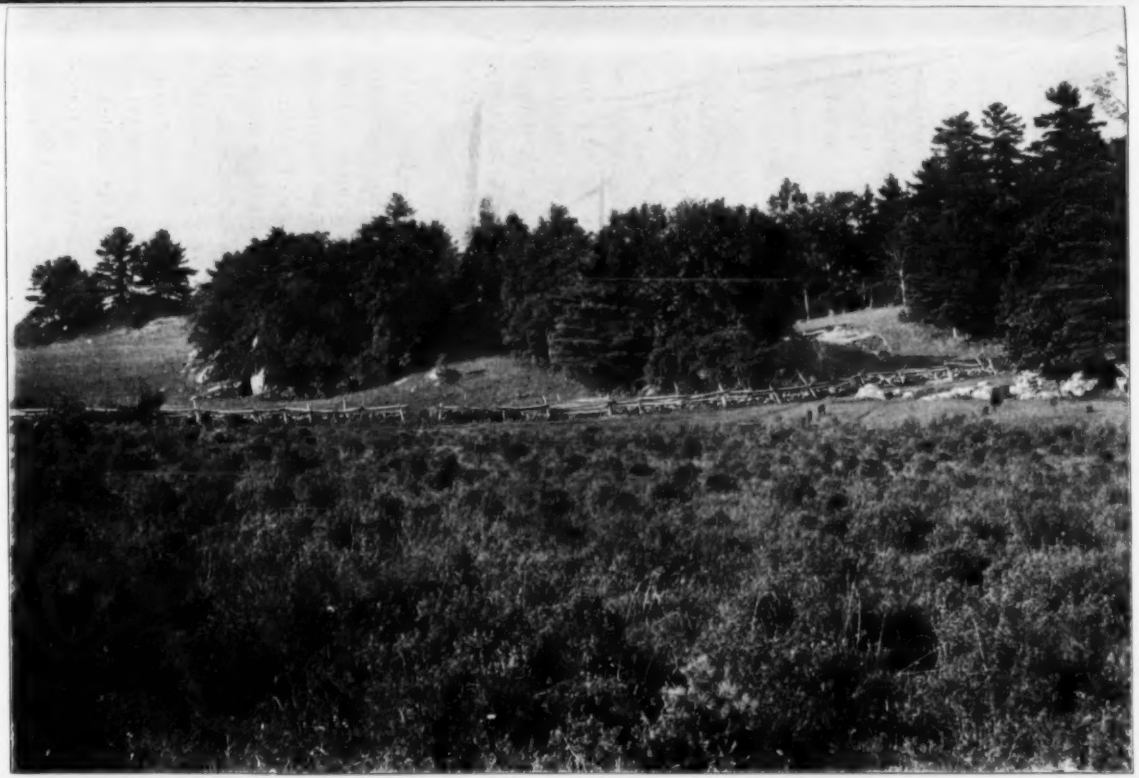

FIG. 2.—Small orographic blocks of silicified limestone arranged *en échelon*. View looking east at a point one and a half miles northwest of Ashley Falls, Mass.

7. *Observation of slickensides.*—While offering contributary evidence in many instances, observation of slickensides is one of the less important methods of locating a fault, and it could hardly be used without other evidence.

8. *Disappearance of outcrops along a rectilinear boundary.*—As already pointed out, little notice seems to have been taken of the way in which outcrops and areas of near-lying outcrops terminate, though in the opinion of the writer such boundaries are full of meaning. When outcrops or groups of outcrops terminate in right lines which are at the same time parallel to the strike of the beds and to the topographic contour lines, no special explanation is required. If they terminate in right lines across the strike of the beds, but along the topographic contour lines, their explanation may be found, either, first, in the erosion history of the region with no dependence upon geologic structure planes; second, in the valley lines as fixed by pre-existing fault planes; or, third, in a fault scarp still in evidence at the locality. If the outcrop boundary is a right line and neither parallel to strike of beds nor to topographic contour lines, it is pretty sure to represent the position of a fault plane.[1] In glaciated areas regard must, however, always be had to essentially local and irregular accumulations of drift as affecting this explanation.

9. *Occurrence of scarps in the more resistant rock.*—In certain areas, at least, of the crystalline schists in which there is accentuated topographic relief, scarps are among the commonest of the physiographic features. In the mapping of the hard-rock geology account has, however, rarely been taken of them, it being perhaps rather generally assumed that their interpretation is the special field of the physiographer and glacialist. If, however, it can be shown that their directions conform to planes of jointing and faulting, their study will furnish some of the most fascinating and instructive lessons for the geologist in the crystalline areas. It is doubtless because their secrets lie hidden in the structure of the underlying rocks that rock scarps as topo-

[1] See HOBBS, *loc. cit.*, pp. 89–91 for special cases of faults fixed by rectilinear boundaries of outcrop.

graphic features have received so little consideration at the hands of the modern school of physiographers.

The perfection of rock scarps will doubtless be dependent primarily upon the resistance of the rock of which they are formed to the agencies of erosion, and to the time that has elapsed since their formation. In dense basalt their life is probably the longest, and the present surfaces will most nearly represent the original fracture planes. It is a fact of general observation that scarps are usually interrupted in such a way as to produce a step-like structure, which suggests in nearly all cases that the throw was distributed over several parallel and near-lying planes. The great cliffs of the Newark basalt of the Connecticut valley produced in an unknown period of post-Newark time, furnish striking illustrations of rock scarps in great numbers and perfection.

The evidence that precipitous rock walls are connected genetically with the fault and joint system of a region — an inherently probable supposition — must be drawn from a study of the direction, not of a single cliff, but of a large number of scarps embracing a considerable area. Accurate topographic maps are most instructive in this regard, but they fail to tell the full story. Photography here comes to the aid of the geologist, not only in recording topographic peculiarities, but in the exposition of them. To give to photographs their full sphere of usefulness, however, it is important to indicate upon the map from what points they were taken and the pointing of the camera at each locality. A photograph common and uninteresting in itself becomes full of meaning in its relation to the map. A character like Fig. 3 entered upon the map and consisting of a circle which incloses the point at which the view was taken, and proceeding from the circle a short arrow to show the camera pointing, will supply the needful information. A figure within the circle refers to the number of the photograph or to the plate of a report, as the case may be.

FIG. 3.

Scarps may, however, be produced in other ways than by faulting. Other agencies most potent to produce them are:

first, in glaciated regions the ice mantle which has carried away blocks from the lee side of elevations lying in its path; and, second, in regions of severe climate, the frost, which has separated blocks and allowed them to roll down steep slopes. A special cause of scarp formation may be the undermining by solution of beds of calcareous rock, which has allowed the overlying beds to fracture and fall. In all cases, however, some earlier structure planes must be assumed along which the block has separated, and these planes may have been either planes of jointing, or faulting, or foliation, or of original bedding. Considering each scarp by itself, therefore, and quite independent of the system of the region, it is more likely to represent a fault in proportion: first, as it does not face in the direction in which the ice mantle moved over the area; and, second, as it is not parallel to a plane of fissility or of bedding (not parallel to the strike).

Study of the southern New England area has shown that cliffs of considerable extent which adhere to a uniform trend often for long distances usually do so, not along a single plane, but by a series of minor zigzags the elements of which are joints or faults of other series combined with the one which corresponds in direction with the general trend of the cliff.[1] Fig. 4 will illustrate the manner in which it is accomplished. Such a composite cliff is shown in Fig. 5. Figs. 1 and 10 must be regarded as showing the same type of structure, but in the next higher orders of magnitude, respectively, within a composite series. This observation of the composite nature of lines of dislocation is regarded as of much significance in showing the genetic connection of faults and joints, as well as in reading the geological structure of an area.

FIG. 4.

10. *Fault gorges.*—In many places, and especially throughout New England, are found deep clefts in the harder rock which are locally known as "purgatories," "devil's dens," "ice-glens," "ice-gorges," etc. The walls of these clefts are nearly or quite

[1] *Vide* BRANNER, "Geology in its Relation to Topography," *Trans. Am. Soc. Civ. Engineers*, Vol. XXIX (1898), p. 63.

FIG. 5.—Cliff essentially rectilinear in direction produced by faulting and composed of many faults of a lower order of magnitude. Southeast wall of the Cobble, Tyringham, Mass. The wall trends N. ± 38° E. for nearly a mile, the smaller faults striking N. ± 38° E., N. ± 70° W., N. ± 10° W., etc.

perpendicular, and their bottoms are occupied, not by a stream, but by an accumulation of great angular blocks composed of the same material as the walls. Deep below this accumulation of blocks one may sometimes thread his way until the ice and snow of the preceding winter are found unmelted even at the end of summer. Such gorges find their simplest explanation in the local depression of a long and narrow orographic block along vertical joint walls (*Graben*), with the accompaniment of much fracturing and dislocation in the block itself. (See Figs. 6 and 7).

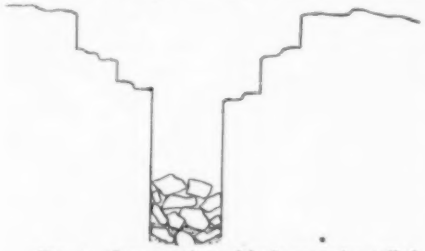

FIG. 6.—Cross-section of fault-gorge (so called "ice-gorge") near Hartsville, Mass. The stippled area represents snow and ice.

11. *Arrangement of surface springs in right lines.*—Since the time of Daubeny and Forbes the locations of springs have been connected with fissures. Peale in his report upon the mineral waters of the United States cites many regions where springs are arranged along fault planes, and, speaking of the Great Basin, says: "A map of the hot springs of the Great Basin would be, to a great extent, a map of its displacements."[1] Regions might be multiplied where essentially the same facts have been observed.

NATURE OF EVIDENCE FOR ESTABLISHING A SYSTEM OF FAULTS.

Observed faults are in parallel and intersecting series—Having made out within a region the presence of a number (larger or smaller) of normal faults, it is next to be determined whether they stand in any relation to one another If a considerable number have been observed, it is likely that some will be found to be parallel, or as nearly parallel as the errors of observation allow. Evidence of this nature is, however, valuable in propor-

[1] PEALE, *Fourteenth Ann. Report U. S. Geol. Survey*, 1894, Part II, pp. 63, 64; see also RUSSELL, *Fourth Ann. Report U. S. Geol. Survey*, 1884, p. 452; HILL AND VAUGHAN, *Eighteenth Report, ibid.*, 1898, Part II, Plate XLVI; HOBBS, *Twenty-first Report, ibid.*, Part III, pp. 91–2.

FIG. 7. —A gorge produced by faults. The "Ice Gorge" near Hartsville, Mass. The view is from within the gorge and looks toward the entrance.

tion as the number of observed faults is large. It has been observed in the Pomperaug valley and fully confirmed by experience gained subsequent to the publication of the report upon that area, that a regular spacing of normal faults is as characteristic of them as it is of joints. It is, therefore, often possible to determine not only the shape but the size of orographic blocks included between series of normal faults within a system or network.

2. *Observed faults are parallel to the joint system.*—In this observation lies the most important evidence that the region as a whole is affected by a system of normal faults genetically connected with its system of joints. Not only is it to be observed whether the two systems are parallel, but, if so, it is to be noted whether any simple relation connects the direction of the individual joint and fault series with the dimensions of the orographic blocks which they have conditioned.

3. *Zigzag topography.*—The study of the topographic map supplemented by observation and by photographs made in the field may show that the physiographic features are bounded by straight elements which coincide in direction with the network determined by the joints and faults. Figs. 9 and 10 represent topography of this type, the one from the intricately faulted Newark area near Meriden, Conn., the other from the crystalline belt of Berkshire county, Mass. A good illustration also of this type of topography is Monument Mountain in Berkshire county, whose main mass is composed essentially of a single fairly uniform formation and is believed to owe its exceptionally rugged topographic development almost solely to its joint and fault planes. (See Fig. 8.)

In the paper which has here been so frequently cited for illustrations of fault structures the writer has used the expression "floating block topography" in reference to a very striking physiographic development, by which are revealed orographic blocks, generally of similar size and shape standing at different altitudes and with bounding fault-planes in evidence as scarps. Fig. 11 displays such a type of physiographic relief. It is to be noted that the blocks of this type (for convenience "unit"

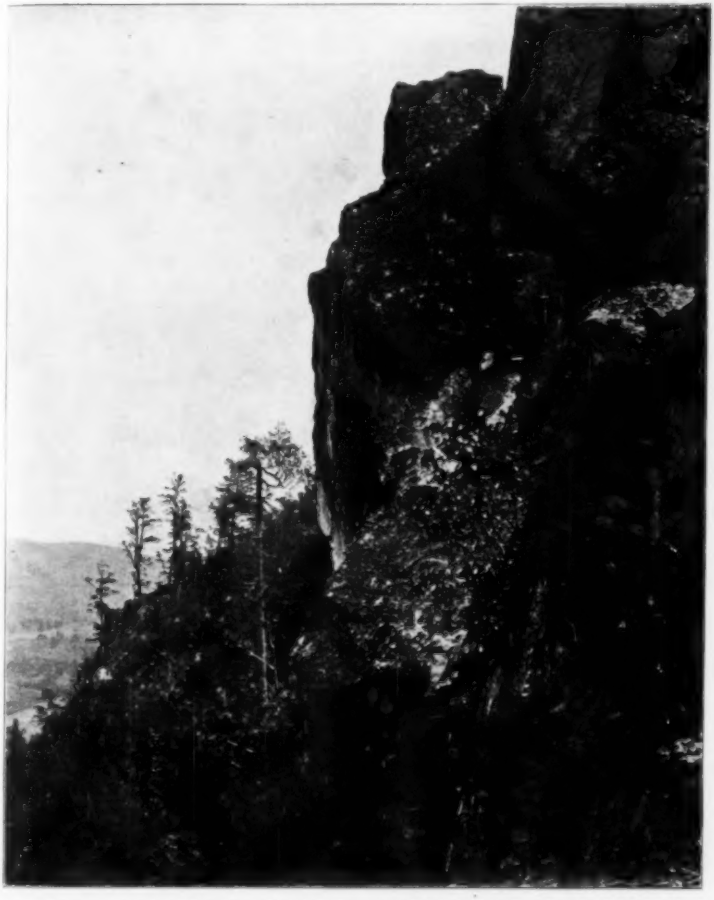

FIG. 8.—Details of topography of Monument Mountain, near Stockbridge, Mass.

blocks, though subdivided by faults and joints) are sometimes grouped into hills—composite blocks—which are spaced over the general surface much like the black squares of a checker board. Fig. 11 exhibits about two-thirds of such a hill in a series of the kind described. Fig. 2 is a detail taken from another hill of the series.

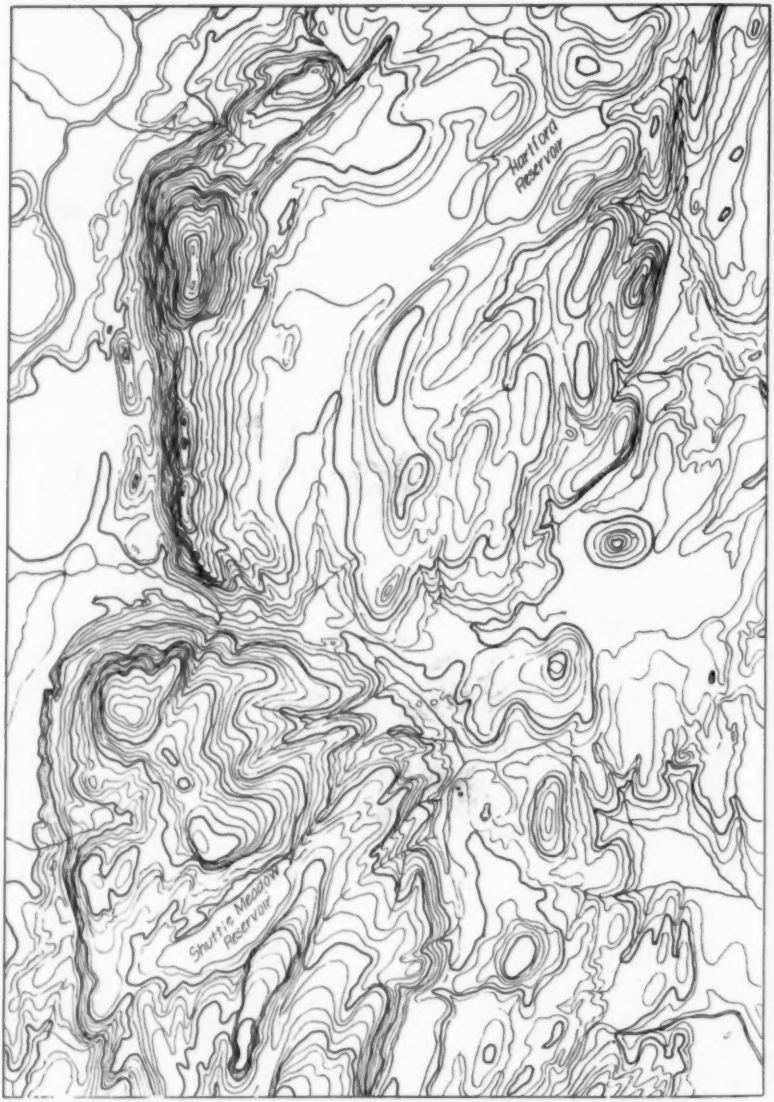

FIG. 9.—Zigzag topography of unfolded but normally faulted Newark rocks. Scale one inch equals one mile. From the Meriden sheet of the map of Connecticut by the U. S. Geological Survey.

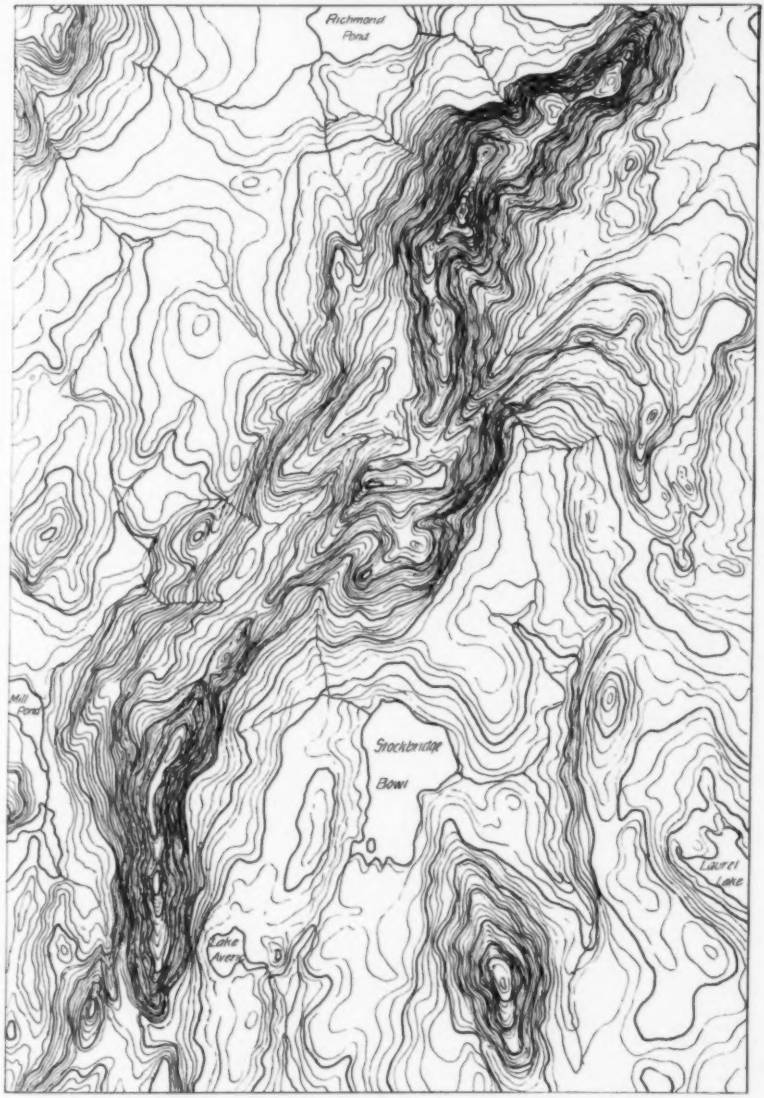

FIG. 10.—Zigzag topography in the crystalline schists. Scale one inch equals one mile. From the Pittsfield sheet of the map of Massachusetts by the U. S. Geological Survey.

4. *The drainage system a network of parallel and interesting series.*—The recognition of the fact that a system of joints and faults has been responsible for the present directions of streams within any region, aside from purely theoretical considerations of the closet naturalist, must be credited to Professor Theodor Kjerulf, the former director of the Geological Survey of Norway. His study of the newer and accurate topographic maps of the country led him to see in the courses of the valleys, lakes and fjords, the lines of dislocations.[1] The occurrence in many areas of similarly regular networks of streams in which the elements are essentially straight lines in parallel series over considerable distances has now long been known, and has been given an adequate explanation by Daubrée as conditioned by the system of fractures (*lithoclases*) of the region, in part by the faults (*paraclases*) and in part by the joints (*diaclases*).[2] Daubrée cites the works of many geologists to show that such stream networks have been observed in many widely separated areas. Since the appearance of his work (1879), numerous other examples have been added.[3] Löwl, in his work on valleys,[4] treats the subject under three heads—fold valleys, fault valleys, and erosion valleys. He mentions the Rhine and the Leine in Germany and the Piave in the southern Alps, as well as other valleys, which are of the fault type.

Daubrée appears to ascribe the orientation of the larger number of stream channels to joints rather than faults, his view

[1] KJERULF, *Geologie des südlichen und mittleren Norwegens*, auth. German ed. by AD. GURLT (Bonn, 1880), pp. 328–34. See, however, in this connection, STUR, "Das Isonzothal," etc., *Jahrb. d. k. k. geol. Reichsanst.*, Vol. IX (1858), pp. 324–66, and plate.

[2] DAUBRÉE, *Géologie expérimentale* (1879), pp. 332–73.

[3] SUESS, *Antlitz der Erde*, Vol. I (1885), p. 339. BRÖGGER, "Spaltenverwerfungen in der Gegend Langesund-Skien," *Nyt Magasin for Naturvidensk.*, Vol. XXVIII (1884), pp. 253–419. "Ueber die Bildungsgeschichte des Kristianiafjords," *ibid.*, Vol. XXX (1886), pp. 99–231. KEMP, "Preliminary Report on the Geology of Essex County," *Report of State Geologist of New York for Year 1893*, Albany, 1894, pp. 438–40. VAN HISE, "Origin of the Dells of the Wisconsin." *Trans. Wis. Acad. Sci.*, Vol. X (1895), 556–60. HOBBS, *loc. cit.* chap. v., also "The River System of Connecticut," JOUR. GEOL., Vol. IX (1901, pp. 469–85).

[4] LÖWL, *Thalbildung* (Prag, 1884), pp. 19–43.

FIG. 11.—"Floating block" topography. Northwest of Ashley Falls, Mass.

being that the course of the stream has been conditioned by the gaping of the joint fissure, and he finds in some instances that the beds on opposite sides of the stream stand at the same level. Löwl takes account of the lateral translation of streams working in inclined strata, and argues that the bed of the stream does not represent the position of the fault, which in many cases can be observed high up upon the slope. Speaking of the valley of the Oder in the Harz mountains, a stream which follows the direction of the Oder fault, he says :

> The Oder valley is therefore nothing more than a performance of the flowing water. Its course along a line of disturbance proves only that this directed the erosion into a definite course.

The writer, by taking account of the great number of parallel faults within a series, would ascribe the courses of the streams within a network more largely to the presence of many long and narrow down-thrown orographic blocks (*Graben*), which have conducted the water like canals.[1] Upon this assumption the equal altitude of the strata upon opposite sides of a valley does not preclude the probability of faults along the bed of the channel. Whatever explanation be offered of the directing of streams upon a large scale by joints and faults, there can be no doubt that streams are of greatest service to the geologist in showing the *directions* rather than the *positions* of lines of dislocation. Regular networks of streams may be assumed to be much more common than the literature of the subject would indicate, for the reason that comparatively little attempt has been made to explain stream directions on the basis of structure planes of the underlying rocks.

5. *Zigzag course of coast lines.*—Evidence of the same kind as that derived from drainage systems is sometimes to be supplied by coast lines, which may disclose the lineaments of a submerged drainage system, the border of a sunken composite orographic block, or a margin of areas of outcroppings. The coast of Scotland between Sutherland and Ross furnishes an illustration.[2]

[1] *Twenty-first Ann. Report U. S. Geol. Survey*, Part III, p. 149, Pl. XVI., Jour. Geol., Vol. IX, p. 483.

[2] Judd, "The Secondary Strata of Scotland," *Quart. Jour. Geol. Soc.* (1873), pp. 131, 134, Pl. VII ; see also Suess, *op. cit.*, Vol. I, p. 269.

It should be by a consideration of all the above outlined methods that the presence or absence of a fault system should be determined for any given area.

METHOD OF MAPPING A CRYSTALLINE AREA DEFORMED BY A SYSTEM OF FOLDS IN CONJUNCTION WITH A SYSTEM OF FAULTS.

The discovery that the beds within a region of crystalline schists have assumed their present attitudes in consequence of deformation of the area by a system of folds in conjunction with one of normal faults, greatly increases, it must be admitted, the difficulties in the way of accurately setting forth the geology upon maps. The question may well be asked whether even with patience and industry the areal distribution of formations can be adequately represented. Where outcrops are abundant and well distributed, and where formations are sharply differentiated petrographically, the difficulties can be overcome; but where gneiss, schist, and quartzite types by reason of gradational members are with difficulty distinguished, even under favorable conditions, their appearance in a fault mosaic will in many cases defy the most skillful worker to unravel.

To fix the order of succession of formations, it will be necessary, not only to exclude the possibilty of an overturn (as by finding the arch of a cross fold), but actually to follow one formation beneath the other.

In other ways the problem of mapping will be simplified. The appearance of formations, first in one areal succession, and again in a different succession not to be accounted for by overturning, will find an adequate explanation. Upon the theory that folding alone has accomplished the deformation of an area of crystalline rocks, geological sections have been strained literally and figuratively beyond the point of rupture. The mechanics of folding is now pretty well understood, and the appearance in geological sections of synclines which have one limb several times the thickness of the other (a not uncommon means of adjusting to theory) finds, it is believed, as little warrant in mechanics as it does in observation.

In explaining an intricately faulted area on the basis of deformation by folding only, it is also the tendency to make geological formations much more heterogeneous than they really are, until at last they have so many different phases that all distinguishing petrographic differences are lost. With the broader interpretation petrography will take a higher place in geological mapping.

It is the intention of the writer in another place to present with the aid of maps and photographs some concrete examples of areas within the belt of crystalline schists where deformation has been accomplished in part by folding and in part by a system of faults.

WILLIAM HERBERT HOBBS.

MADISON, WIS.
September 1, 1902.

Reviews.

PRE-CAMBRIAN SUMMARIES FOR 1901.

Van Hise[1] describes the geology of the Lake Superior iron ore deposits. The general succession of formations in the iron-bearing districts appears in the following table:

Mesabi.	Penokee-Gogebic.	Vermilion.
Keweenawan: Great basal gabbro and granite, intrusive in all lower formations.	Gabbros, diabases, etc.	Great Gabbro.
Upper Huronian (Mesabi series): Virginia slate (upper slate formation). Biwabik formation (iron-bearing formation). Pokegama formation (quartzite and quartz-slate formation).	(Penokee-Gogebic series): Tyler slate (upper slate formation). Ironwood formation. (iron-bearing formation.) Palms formation (quartz-slate formation).	Animikie series: Upper slate formation. Gunflint formation (iron-bearing formation).
Lower Huronian: Granite intrusive in lower formations. Slate-graywacke–conglomerate formation. (Equivalent to the Ogishke and Knife formations of the Vermilion district.)	Bad River limestone (cherty limestone formation).	Intrusives. Knife slates. Lower Huronian iron-bearing formation. Ogishke conglomerate.
Archean: Greenstones, hornblende schists, and porphyries.	Granite and granitoid gneiss. Schists and fine-grained gneiss.	Vermilion series: Intrusive granites, porphyries, and greenstones. Soudan formation (the iron-bearing formation). Ely greenstone, an ellipsoidally parted basic igneous and largely volcanic rock.

[1] "The Iron-Ore Deposits of the Lake Superior Region," by C. R. Van Hise, assisted in Mesabi and Vermilion sections by C. K. Leith and J. Morgan Clements respectively, *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part III, 1901, pp. 305-434; with geological maps.

MARQUETTE.	CRYSTAL FALLS.	MENOMINEE.
Upper Marquette: Michigamme formation (locally replaced by Clarksburg volcanic formation). One might divide Michigamme sedimentary formation into three parts: (*a*) upper slate member, (*b*) iron-bearing member, (*c*) lower slate member. Ishpeming formation, consisting of two members; the Bijiki schist (in western part of district), and the Goodrich quartzite, containing detrital ores at its base.	Michigamme formation, containing an iron-bearing horizon not separated in mapping for much of the district, but in a southeastern part having as lower formations (*a*) the Groveland formation, and (*b*) the Mansfield slate.	Upper Menominee: Hanbury slate, bearing in lower portions calcareous slates, etc., containing siderite and iron oxide. Vulcan formation, consisting in descending order of three members: (*a*) Curry member (iron-bearing); (*b*) Briar slate; (*c*) Traders member (iron-bearing).
Lower Marquette: Negaunee formation (the chief iron-bearing formation). Siamo slate, containing inter-stratified amygdaloid. Ajibik quartzite. Wewe slate. Kona dolomite. Mesnard quartzite.	Hemlock formation. Negaunee formation (in northeastern part of the district). Randville dolomite. Sturgeon quartzite.	Lower Menominee: Negaunee formation (in small patches). Randville dolomite. Sturgeon quartzite.
Granite, syenite, peridotite. Kitchi schist and Mona schist, the latter banded, and in a few places containing narrow bands of iron-bearing formation. Palmer gneiss.	Granite.	Granites and gneisses. Quinnesec schist.

Van Hise and others[1] have discussed the geology of the Lake Superior region in previous reports, both general and detailed. The present report is a summary of the earlier reports,

[1] See especially "Principles of Pre-Cambrian Geology," in *Sixteenth Annual Report*, Part I, *U. S. Geol. Surv.*; pp. 571–874; *Bulletin* No. 86, *U. S. Geol. Surv.*; *Monographs U. S. Geol. Surv.*, Vol. XIX, XXVIII, XXXVI; and *Folio U. S. Geol. Surv.*, No. 62.

but it contains in addition many new features of interest. Attention will be directed only to such conclusions as are new or vary from those given in the preceding reports.

In the Vermilion district the great Stuntz conglomerate and equivalent rocks have been found to lie unconformably under the Animikie series, which has been referred to the Upper Huronian by the United States Geological Survey, and thus the Stuntz conglomerate is correlated with the Lower Huronian series instead of with the Upper Huronian, as in former reports. The underlying greenstones, green schists, and iron formation, the latter of sedimentary origin, are thus thrown into the Archean.

In the Mesabi district the Keewatin of the Minnesota Survey, which was in large part classed as "Archean" by the United States Geological Survey and recognized by all as being unconformably below the Animikie, is subdivided on the basis of recent work in the district by C. K. Leith into an upper series of graywackes, slates and conglomerates, correlated with the Lower Huronian, and a lower basement complex, consisting mainly of greenstones and green schists, correlated with the Archean. This correlation is based on the equivalence of the Animikie with the Upper Huronian long maintained by geologists of the United States Geological Survey.

In the Marquette district certain jaspers and associated cherty and slaty rocks found intimately associated with the basement rocks of the Archean, and previously supposed to be Huronian rocks infolded with the Archean, are now themselves called Archean.

In the Michipicoten district of Canada the iron formation, and associated greenstones and green schists, are correlated respectively with the iron formation with associated greenstones and green schists of the Vermilion district, and are therefore classed as Archean.

The iron ores of the Lake Superior region are supposed to have originated from iron carbonate in all districts outside of the Mesabi. In the Mesabi district the ores have mainly resulted from the alteration of a green ferrous silicate in small granules

as first shown by Spurr, but the ores have come also in small part from the alteration of iron carbonate which is correlative in origin with the green granules. The ferrous silicate granules are believed not to be glauconite, as they were named by Spurr.

Comment.—The reference to the Archean of sedimentary iron formation rocks in the Vermilion, Michipicoten, and Marquette districts is a source of surprise and comment among many interested in pre-Cambrian stratigraphy. The term "Archean" has been consistently used by the United States Geological Survey for the "basement complex" of the Lake Superior region, consisting essentially of igneous rocks, and all pre-Cambrian sedimentary rocks have been referred to the Algonkian. In survey reports on Lake Superior geology there have been slight variations from this usage, for certain "tuffs" and "gneisses" (Kitchi and Palmer) classed as Archean in the Marquette district have been referred to as partly sedimentary. In the present paper Van Hise has gone a step farther and included sedimentary formations of considerable importance in the Archean. The basal complex rocks of igneous origin are very closely associated with sedimentaries, and in many areas scarcely to be discriminated in the mapping. On the other hand, both igneous and sedimentary rocks are sharply separated by a profound and conspicuous unconformity from sediments called Huronian or Algonkian. In mapping in the Lake Superior region it has been found convenient, and in many cases necessary, to class together all rocks, igneous and subordinately sedimentary, below this well recognized unconformity at the base of the Huronian. Van Hise has chosen to retain the term "Archean" for this structural unit. It is thought by many geologists that it would have been preferable to have extended the term "Algonkian" to include the sediments beneath the well recognized Huronian, thus adding one more series to the Algonkian, keeping in the Algonkian all recognizable sedimentary rocks beneath the Cambrian, and leaving the term Archean for the true igneous basement complex (if there be such a thing). If, because of the close association of the basement igneous rocks and the sedimentary rocks beneath the Huronian, it were found desirable to consider the basal igneous

and sedimentary rocks together as a structural unit under one term, the same geologists suggest that some local term might have been applied to the basal complex in the Lake Superior country instead of the general term "Archean."

The correlation of the upper series of the Mesabi and Penokee-Gogebic districts (which are agreed by all to be equivalent to the Animikie series) with the Upper Huronian of the original Huronian area of the north shore of Lake Huron, first worked out by Logan and Murray, is also questioned by certain Canadian and Minnesota geologists, who believe that these series are younger than the true Huronian of the original Huronian area. They would correlate Van Hise's Lower Huronian with the Upper Huronian of the original Huronian area, and thus Van Hise's Archean would in large part fall into their Lower Huronian.

Finally, it is maintained by Canadian geologists and others that the granites classed by Van Hise as Archean are intrusive into the Huronian rocks. Van Hise's position is that the granitic complex contains rocks both older and younger than the Huronian sedimentary rocks; that the fact that certain granites are clearly intrusive into the sediments does not militate against the evidence offered by basal conglomerates that another, and perhaps larger portion, is really unconformably below the Huronian rocks.

It would not be possible in a summary of this nature fully to summarize the arguments and reasons which have led Van Hise to the conclusions outlined in the above paper. He has in preparation a final monograph on Lake Superior geology in which these and allied questions are fully discussed in the light of recent developments. In view of Van Hise's close and exhaustive work in the Lake Superior region, which is in many respects a type pre-Cambrian region, and the long period of time during which this work has been carried on, his final statement of his position with reference to the geology of the area will be awaited with interest.

Coleman[1] reports on an examination of the "Lower Huronian"

[1] "Iron Ranges of the Lower Huronian," by A. P. COLEMAN, *Tenth Report of the Bureau of Mines*, Ontario, 1901, pp. 181–212.

iron ranges at Shining Tree Lake, Clear Lake, Sault Ste. Marie, Aberdeen Additional, Batchawana Bay and northward, Michipicoten Harbor, and the Helen mine, all in Ontario. As a result of this work it is possible to greatly extend the areas of Lower Huronian iron formation rocks in Ontario. Their general distribution is stated by Coleman as follows:[1]

It has long been known that the Vermilion iron range of Minnesota crossed the boundary into Ontario at Hunter's Island, and jaspery iron ores have been found at various points in that region—e. g., by W. H. C. Smith on Jasper Lake, where banded jasper and hematite have a width of forty or fifty feet. Brecciated jasper and iron ore are known from the Mattawin region also, and from a number of points to the north, as noted by Dr. Bell; but in the latter case the deposits may be of Animikie age, and therefore not to be included here.

In the band of Huronian mapped as running eastward from Lake Nipigon in the direction of Long Lake, a deposit of banded jasper and iron ore has been examined by Mr. J. Watson Bain, near the mouth of Black Sturgeon River, and an extension of it is reported from the same stretch of Huronian, north of Long Lake. To the south of this, ten or twelve miles from the mouth of Pic River, the other type of deposit is found, brecciated granular silica with magnetite.

The Michipicoten range is separated from this by a wide area of Laurentian, and the first outcrop occurs about fifteen miles west of Iron Lake, near the headwaters of Dog River. It is jaspery and cherty, with interbanded magnetite and hematite; but on the eastward extension of the line across Dog River one finds the granular variety mixed with magnetite near Paint Lake. A few miles to the north what appears to be a parallel band has been traced by Professor Willmott and has been found to include promising ore deposits. The whole extent of this range, as traced by Professor Willmott, is about twenty-seven miles, the longest continuous stretch in Ontario.

Farther to the east not much has been reported until Magpie River is crossed by Speight's east and west base line, where a range of hills with jaspery and cherty material interbanded with ore runs two or three miles southeasterly. Six or eight miles to the south the iron-bearing rocks are found again near Park's Lake, and can be followed four or five miles west and southwest, including the promising Josephine mine now being developed. In the same direction is Lake Eleanor, where siderite and the banded silica are found; and two miles west is the Boyer Lake property described before, the band having a length of about a mile and a quarter and running east and west. Ten miles to the southwest is the Gros Cap deposit of sandy and

[1] Pp. 200–202.

quartzitic rock interbanded with hematite, sunk upon many years ago, but not developed to any great extent as a mine. Rock of the same sort has been found near Michipicoten Post and Cape Choyé, Professor Willmott having ascertained the latter range to be six miles long, though without ore so far as known.

Once more a wide band of Laurentian intervenes, the next examples of the iron formatian occurring sixty-five miles to the south, near Batchawana Bay, where two bands run nearly parallel to one another, about east and west, each from four and a half to five miles long, with reported finds some miles to the east on Harmony River, and to the west near Pointe aux Mines on Lake Superior. The two bands differ in character, the one to the south being of jasper with hematite and that to the north cherty or quartzitic with magnetite.

The next known locality, about nine miles northeast of the Sault, is of the same character as the last, and is enclosed in Laurentian rocks instead of Huronian or basic eruptives as in most other localities. The wide band of Huronian between the "Soo" and Sudbury is not known to contain any rocks of the iron formation, though the large numbers of bright red jasper pebbles in the conglomerates of the upper Huronian must have a source somewhere in the region.

In the considerable area of Huronian north of Woman River, on the main line of the Canadian Pacific railway, jaspery iron ore has been reported, but no details have been obtained regarding it. To the east of this Mr. Whitson has examined a jasper range running several miles in a southeasterly direction, between the upper end of Onaping Lake and Meteor Lake; and about twenty-five miles to the northeast is a range of jasper, chert and impure siderite with magnetite and limonite of the Shining Tree Lake region, running somewhat west of north and south of east for three and a half miles, and perhaps for double that distance. A few miles farther northeast jasper is reported from one of the chain of lakes belonging to Montreal River, and still farther to the north at Night Hawk Lake.

In the southern portion of this Huronian region rocks of the kind occur on the northwest shore of Lake Wahnapitae as dull red jasper and chert with magnetite, and extend west in the Laurentian in Hutton and Wisner townships. It may be that there are two separate bands here, the southern one east and west and the northern one north and south, the latter the more important, as containing what are said to be large deposits of magnetite.

Of the iron range to the northeast of Lake Wahnapitae, Professor Miller reports that "starting from Lake Temiscaming on the east the first outcrop, which is of small size and was not visited by me, is situated a short distance east of the east end of Rabbit lake. The next outcrops occur along the northeast shore of the east end of the northeast arm of Lake Temagami, the band here stretching from near Snake Lake west to Tetapaga. Outcrops

occur also near the end of Matagama Point. A belt lies parallel to these outcrops to the northward and runs, with breaks here and there, from near the west side of Net Lake to Kokoko Lake.

"Then there is an isolated belt stretching from near Cross Lake, north of west, past the southern extremity of the south arm of Temagami to the southwest arm of the same sheet of water, and to the westward outcrops are found on Emerald Lake. A band, more or less broken, runs along the north of Lake Wahnapitae northwest into and through part of the township of Hutton."

He adds that "in nearly all cases the iron ore, magnetite, is intimately interbanded with jasper, which varies much in color in different parts of the field. In some outcrops the magnetite is pretty massive, and if situated near a railroad could apparently be worked profitably. The breadth of the band of interlaminated material is sometimes 500 feet or more. It is at times much bent and fractured, having been disturbed by igneous intrusions, and some of these disturbed bands give evidence of being worthy of more careful prospecting than we are able to do in the limited time at our disposal."

Belts of iron-bearing rocks, like those described in this report, are found also in Quebec, though up to the present little has been done in searching them out. Mr. McOuat has reported from the eighth portage of the Quinze, on the headwaters of the Ottawa above Lake Temiscaming, an ore which forms "layers from the thickness of paper to about an inch, and is interlaminated with similar layers of whitish-gray and dull red fine-grained quartzite. The iron ore constitutes probably from a fourth to a third of the whole, and as the thickness of the whole band is about thirty feet, the total thickness of the layers of iron ore would probably not be less than eight feet." This is evidently the same type of deposit as those described from Ontario.

Mr. A. P. Low describes jaspery iron ores which he compares with those of Michigan, and also cherty iron carbonates from various points in Labrador, and probably some of these occurrences are Lower Huronian, though from his description it is clear that most of them are of Animikie age.

From the statement just given it will be seen that bands of jaspery cherty, or sandstone-like rock interbanded with magnetite, hematite, or limonite and sometimes associated with siderite, occur from point to point across the whole of northern Ontario, with lengths varying from a hundred feet to twenty-seven miles. Almost all of the important areas mapped as Huronian have more or less extensive belts of this rock, and in several cases isolated patches or strips of it occur in the Laurentian, as if these were remnants left when less resistant Huronian rocks had disappeared. These portions contained in the granite are never red jasper, but generally cherty or quartzitic, and the iron ore is magnetite, whereas in Huronian areas we generally find jasper or granular silica with hematite or limonite.

Associated with the iron formation rocks above mentioned,

and also in other areas, are conglomerates containing numerous fragments of iron formation rocks, and therefore believed to be of Upper Huronian age. In addition to the conglomerates whose distribution was described in a previous report,[1] conglomerates are known in the following areas:

The Doré[2] river conglomerate, which contains many pebbles of sandstone and chert, has been found to extend within a few miles of the Helen mine, and to be about twenty-four miles in length from the mouth of Dog River on the west where it begins. In sections of some of the pebbles siderite has been found, proving that materials exactly like those at the mine were rolled on the inter-Huronian beach before the conglomerate was formed. Similar conglomerates have been found at other points in this Huronian area; for instance, two or three miles north of Coetz Lake, not far from the Josephine mine.

Conglomerates have not yet been found nearer the Batchawana jasper and chert beds than at the north end of Goulais Bay, fifteen miles to the south, where Murray mapped jasper conglomerate many years ago. The extensive bands of quartzitic conglomerate containing blood-red jasper pebbles in the original Huronian region, extending from Lake George almost to Thessalon, about thirty miles, and found in several different bands, some of them quite to the north of those mapped by Murray, have never been accounted for, since no jasper has been found nearer than Batchawana, more than fifty miles to the northwest, and there the jaspers are much duller in color. The accompanying black chert pebbles, which are equally common, might have been supplied by the cherty iron ore band nine miles northeast of the Sault Ste. Marie, mentioned in a previous part of this report, though this is about ten miles from the nearest of the conglomerates. The region is, however, little known beyond the few miles of settled country along the St. Mary's River and the north shore of Lake Huron, and future exploration may solve the problem.

Numerous conglomerates occur along the same stretch of Huronian to Sudbury, but no jasper or chert pebbles are known in them, though they are found in quartzites and graywackes somewhat farther east on Lake Matagamashing, not far from the jasper iron ore belt north of Lake Wahnapitae. Small amounts of jasper conglomerate have been noted northward from this, and a graywacke conglomerate containing jasper and chert pebbles extends for some miles parallel to the Shining Tree Lake iron range but a mile or two to the west.

East of Lake Wahnapitae conglomerates with jasper are known at various points to Lake Temiscaming, and also on the Quebec shore of that lake

[1] *Bureau of Mines*, 1900, pp. 180-86, and *Bull. G. S. A.*, Vol. XI, 1900, pp. 107–14. See Summaries, JOUR. GEOL., Vol. IX, 1901, pp. 447-9.

[2] Pp. 203–4.

near Baie des Perés. That they extend still further to the east, is shown by Low's report on Labrador, where conglomerates with Laurentian bowlders and jasper bowlders and pebbles seem to be common.

It is not certain, of course, that every one of these rocks containing pebbles of jasper, chert, or sandstone is a basal conglomerate of the Upper Huronian, but many of them undoubtedly are, and in the majority of cases the source of their pebbles is found in adjoining bands of siliceous iron-bearing rocks which may be looked on as belonging to a horizon near the top of the Lower Huronian, Van Hise's Mareniscan.

Willmott[1] describes the geology of the Michipicoten area northeast of Lake Superior. He makes the succession from the base up as follows:

1. Lower Huronian green schists. Some of these are undoubted lava flows showing the characteristic elliptical structure described by Clements as occurring in the Hemlock formation of the Crystal Falls district. At a number of points agglomerates are found, as at Little Gros Cap fish station, north of Goetz Lake, east of Manitowoc, and elsewhere. Commoner occurrences are the various green schists, chlorite, hornblende, mica, and sericite schists. Presumably all these schists are derived from lavas, basic and acidic. The dip of the schists is always nearly vertical and the strike follows closely the line of contact with the granite, to be described later.

2. Lower Huronian sediments. The most characteristic of these is a belt of ferruginous chert, which has been found at intervals for about sixty miles. This rock consists of banded hematite and silica with usually some residual carbonate of iron. The bands vary from one-tenth of an inch in thickness up to several inches. The silica is sometimes very like loaf sugar; again it is like quartzite, chert, or jasper. Red jasper is not infrequent. The hill at the back of the Helen mine is a huge mass of siliceous carbonates. The rocks, as a whole, and the mode of occurrence of the ore, are strikingly like the Lower Huronian iron formations of Marquette and Tower. Besides the iron formation, beds of carbonaceous shales and limestones have been recognized at several points. Shale occurs interstratified

[1] "The Michipicoten Huronian Area," by A. B. WILLMOTT, *American Geologist*, Vol. XXVIII, 1901, pp. 14–19.

with the ferruginous chert at Iron Lake. Near Paint Creek and at Eleanor Lake it has also been found. Whether it always underlies the iron formation is undetermined, but it probably does not. The cherty limestone has been traced in a fairly continuous line from the Helen mine to the east of Park's Lake, a distance of twelve miles.

3. Upper Huronian sediments. These consist of schist-conglomerate. Coleman describes the bowlders as "granites most frequently, then quartzites, or sandstones with pebbles generally small, next green schists, then felsite schists and porphyroids, and finally a few gneisses, but none of the Laurentian type." A thin section of one of the quartzite pebbles showed considerable carbonate, proving that it undoubtedly came from the iron formation. This conglomerate has been traced pretty continuously for thirty-eight miles in a semicircular belt around the central granite boss. At many points, as at Iron Lake, Dog River, Doré River, Wawa Lake, it contains pebbles from the very characteristic iron formation. This fixes its age as Upper Huronian.

4. Laurentian granite, intrusive in the Huronian rock. The granite is in undoubted eruptive relations with the conglomerate along the shore of Superior, for example a few miles west of the Doré. A mile and a half up the Magpie, a boss of granite is in eruptive contact with the conglomerate, and although it may not be of the same age as the larger boss three miles to the northwest, it probably is. In the opposite direction a succession of granite gneiss bosses intrusive in the schists are found, for six miles, after which the granitoid gneiss occurs without interruption for over a hundred miles.

Comment.—Van Hise[1] has referred Willmott's "Lower Huronian" green schist and iron-bearing formation to the Archean, and has referred his "Upper Huronian" schist-conglomerate series to the Lower Huronian. Indeed he would so refer most of the conglomerates described as Upper Huronian by Coleman in the article above summarized. The Michipicoten series show close similarities in structure and lithology to portions of the Archean and Lower Huronian series, respectively, of the Ver-

[1] See summary of Van Hise's report on a preceding page.

milion iron-bearing district of Minnesota. There is little dispute as to the equivalence of the series in the two districts, but there is dispute as to their correlation with the original Huronian series of the north shore of Lake Huron, and thus as to their nomenclature. At the east end of the Vermilion district they have been proven to underlie unconformably the Animikie series of the Mesabi district and its eastward continuation to Thunder Bay on Lake Superior, which has been correlated by Van Hise and others with the Upper Huronian of the original Huronian area, but which the Canadian geologists and others regard as younger than the true Upper Huronian. As already noted, Van Hise has in preparation a final monograph on Lake Superior geology in which the position of the United States Geological Survey with reference to the correlation of these series in the light of recent work will be fully stated.

Bain[1] describes the iron belt of Lake Nipigon, devoting his attention mainly to economic and petrographic features. The stratigraphical features are covered in the general report of Coleman summarized on a previous page.

Miller[2] describes the iron ores and associated rocks of the area adjacent to Lake Temegami and of the Lake Wahnafutae and Hutton areas to the west, all in the Nipissing district of Ontario. The Temegami has been previously mapped and reported upon by A. E. Barlow.[3] Miller's discussion of the general geology of this area follows that of Barlow, with minor additions and corrections.

Winchell[4] publishes a geological atlas of the state of Minnesota with synoptical description of plates. This volume contains maps and general conclusions found in Volumes IV and V of the Minnesota Survey, summarized in this JOURNAL, Vol. IX, pp. 79–86. One additional map is published, a general geological map of the state.

[1] "The Iron Belt on Lake Nipigon," by J. W. BAIN, *Tenth Report of Bureau of Mines*, Ontario, 1901, pp. 212–14.

[2] "Iron Ores of Nipissing District," by WILLET G. MILLER, *Tenth Report of the Bureau of Mines*, Ontario, 1901, pp. 160–80.

[3] *Annual Report Geol. Survey of Canada*, Vol. X, Part I, for 1897, pp. 302. Summerized, JOUR. GEOL., Vol. VIII, 1900, pp. 439–41.

[4] *The Geological and Natural History Survey of Minnesota*, Vol. VI, 1900–1.

Duparc[1] describes the copper-bearing (Keweenawan) rocks of the northwest extremity of Keweenaw Point, Michigan. The article is throughout merely a summary of previous reports on this area by the geologists of the Michigan and United States Survey, and this moreover without a single reference to such reports.

Hall[2] describes the Keweenawan rocks south and southwest from Duluth, along the St. Louis and St. Croix rivers, and shows that a series of alternating lava flows and sediments lie in a synclinal northeast-southwest trough, the western border of which is marked by a profound fault. To the east of the fault the Keweenawan rocks are highly tilted to the southeast, while to the west of it the Cambrian rocks are much broken up. The relations of the fault to the distribution of the flows and analogy with other volcanic regions seem to show that the fault was a plane of weakness along which most of the lavas were originally erupted. The faulting was pre-Cambrian, Cambrian, and post-Cambrian, as shown by the fact that in some places the Cambrian rests horizontally upon the upturned Keweenawan rocks, and in others is much broken up.

Hall[3] describes and maps the slates and associated rocks in the vicinity of Cloquet and Carlton on the St. Louis River, and certain hornblendic and micaceous schists associated with granite and diabase to the west along the Mississippi and Snake rivers. He maintains that the slates and graywackes to the east and the hornblendic schists to the west belong to one and the same series, and that the schists have resulted from the metamorphism of graywacke and slate by the intrusion of granite. Still later intrusions of diabase have cut both the granites and the slates. Accepting Spurr's statement that the Carlton slates are Keewatin or Lower Huronian, the con-

[1] "Note sur la Region Cuprefere de l'extremite Nord-Est de la peninsule de Keweenaw (Lac superieur)," par LOUIS DUPARC, *Archives Sci. Physique et Nat.*, Tome X, 1900, p. 21.

[2] "Keweenawan Area of Eastern Minnesota," by C. W. HALL, *Bulletin of the Geological Society of America*, Vol. XII, 1901, pp. 313–42, Pls. 27–28.

[3] "Keewatin Area of Eastern and Central Minnesota," by C. W. HALL, *Bulletin of the Geological Society of America*, Vol. XII, 1901, pp. 343–76, Pls. 29–32.

clusion is reached that the schists to the southwest are Lower Huronian, and that the intruding granites are post-Lower Huronian. If this conclusion be correct, the granites and schists of the central and eastern portions of Minnesota must be mapped as Algonkian rather than Archean, as in the past.

Ami[1] briefly summarizes the salient features of the geology of the principal cities of eastern Canada, including St. John, Ottawa, Quebec, Montreal, and Toronto.

Ami[2] summarizes the geology of Canada, and indicates the meaning and correlation of the principal terms employed in Canadian geological nomenclature.

Ells[3] sketches the development of geological work in the province of Quebec.

Ells[4] describes and maps the geology of the Three Rivers sheet of the "Eastern Townships" map, Province of Quebec. Archean rocks occupy most of the northwestern portion of the area north of the St. Lawrence River. A portion of this area, including anorthosite masses, has previously been described by Adams.[5]

The great mass of the rocks seen pertain to the Grenville series, rather than to the so-called "Fundamental" gneiss. The composition of the Grenville series, with its crystalline limestones and with rusty gneiss bands, very closely resembles that met with in the lower Ottawa district, but the calcareous members are much less widely developed. There are also large areas of anorthosite, red granite, augen-gneiss and masses of green pyroxenic diabase. Quartzite is an important component of this series, and large areas of this rock, similar to that found along the

[1] "On the Geology of the Principal Cities of Eastern Canada," by HENRY M. AMI, *Trans. Royal Soc. of Canada*, Vol. VI, 1900; sec. iv, pp. 125–64.

[2] "Synopsis of the Geology of Canada," by HENRY M. AMI, *Trans. Royal Soc. of Canada*, Vol. VI, 1900, sec. iv, pp. 187–225.

[3] "Problems in Quebec Geology," by ROBERT W. ELLS, *Record of Science*, Vol. VII, 1898, pp. 480–502.

[4] *Geol. Surv. of Canada, Annual Report*, New Series, Vol. XI, for 1898, pp. 5 J–70 J; with geological map.

[5] *Geol. Surv. of Canada*, Vol. VIII, Part J. Summarized, JOUR. GEOL., Vol. VII, p. 401.

Ottawa, are found associated with the gneiss as far north as the northern limit of the map-sheet.

The definition of the so-called fundamental gneiss is, as a matter of fact, not always possible in this district. If the latter appears at all, it must be along the crests of some of the numerous north-south anticlines, which are generally low, the rocks over a large area being inclined at low angles. The prevailing gneiss is a grayish and hornblendic variety, generally quartzose, and with frequent bands in which garnets are abundant.

The anorthosites are intrusive in the Grenville series. The Grenville series are correlated with the Hastings series and both are equivalent to the Huronian. The Fundamental gneiss is Laurentian.

Bell[1] describes and maps the geology of the Baffin Land shore of Hudson Strait.

The rocks of the northern side of Hudson Strait from North Bay to Chorkback Inlet and inland to Lake Mingo consist of well stratified hornblende and mica-gneiss, mostly gray in color, but sometimes reddish, interstratified with great bands of crystalline limestones, parallel to one another and conformable to the strike of the gneiss, which in a general way may be said to be parallel to the coast in the above distance. The direction, however, varies somewhat in different sections of the coast. All are of Laurentian age.

The distinguishing feature in the geology of the southern part of Baffin Land is the great abundance, thickness and regularity of the limestones associated with the gneisses. At least ten immense bands, as shown on the accompanying map, were recognized, and it is probable that two others, discovered in North Bay, are distinct from any of these. There would, therefore, appear to be twelve principal bands as far as known, to say nothing of numerous minor ones, between Icy Cape and Chorkback Inlet. Their total thicknesses may be 30,000 feet, or an average of 2,500 feet for each of the principal bands. These rocks are correlated with the Grenville.

[1] *Geol. Surv. of Canada, Annual Report*, New Series, Vol. XI, Part M, for 1898, pp. 5 M–38 M; with geological map.

Low[1] describes and maps the geology of the south coast of Hudson Strait and the west and south shores of Ungava Bay. Granite and gneiss of various ages occupy three-fourths of the coastal area. Associated with them are gabbros, diabases and other greenstones, cherts, quartzites, shales, and slates. All are provisionally referred to the Archean.[2] Flat-bedded Cambrian rocks rest with apparent unconformity upon the crystalline complex.

Tyrrell and Dowling[3] describe and map the east shore of Lake Winnipeg. The rocks are all Archean and the great preponderance of gneisses and granites of the Laurentian is the chief feature. Small areas of Huronian greenstones and schists occur in two localities, one on Lac du Bonnet and the other at the mouth of Wannipegow River.

In an account of a trip from Edmonton through Yellow Dog Pass, in the Rocky Mountains, to Canoe River a tributary of the Columbia River, McEvoy[4] describes and maps Shuswap rocks, of Archean[5] age, occurring on Mica Mountain near the western end of the route. The series includes dark glittering mica-schist, easily weathering, thinly foliated garnetiferous mica-schist, with a high percentage of mica and garnet, hard garnetiferous mica-schist in massive beds, bands of dark fine-grained micaceous rock apparently of eruptive origin, and layers of fine-grained gneiss which, in some instances at least, is certainly intrusive. The whole series, while differing somewhat from the Shuswap series of the southern interior of British Columbia, shows the main characteristics of that series and may be classed as such. The age of this series as given by Dr. Dawson is Archean.

[1] *Geol. Surv. of Canada, Annual Report*, New Series, Vol. XI, Part L, for 1898, pp. 5 L–47 L; with geological map.

[2] Pre-Cambrian.

[3] *Geol. Surv. of Canada, Annual Report*, New Series, Vol. XI, for 1898, pp. 5 G–98 G; with geological map.

[4] *Geol. Surv. of Canada, Annual Report*, New Series, Vol. XI, for 1898, pp. 5 D–44 D; with sketch map.

[5] Pre-Cambrian.

Dawson[1] describes the geology of the Rocky Mountain region in Canada. The oldest rocks of the region belong to the Shuswap series of Archean[2] age. The Shuswap series characterizes considerable areas of the Selkirk, Columbia, and adjacent ranges in the southern part of British Columbia. It is known also in the Cariboo mountains and near the sources of the North Thompson and Fraser, about latitude 53°. It is again well developed on the Finlay River, where the country has been geologically examined, between the 56th and 57th parallels of latitude. Northward to this point these rocks appear to be confined to a belt lying to the west of the Laramide range and to come to the surface seldom, if at all, in that range. Further north similar rocks occur in the Yukon district in several ranges lying more to the west, but still with nearly identical characters, in so far as they are known. The Shuswap series includes highly metamorphosed sediments with perhaps the addition of contemporaneous bedded volcanic materials. They are grayish mica-gneisses, with some garnetiferous and hornblendic gneisses, glittering mica-schists, crystalline limestones and quartzites. Gneisses in association with the last mentioned rocks often become highly calcareous or siliceous and contain scales of graphite, which are also often present in the limestones. These bedded materials are, however, associated with a much greater volume of mica-schists and gneisses of more massive appearance, most of which are evidently foliated plutonic rocks, and are often found to pass into unfoliated granites. The association of these different classes of rocks is so close that it may never be possible to separate them on the map over any considerable area. The granites may often have been truly eruptive in origin, but the frequent recurrence of quartzites among them in some regions indicates that they are at least in part, the result of a further alteration of the bedded rocks. The original bedded portions of the series closely resemble those of the Grenville series of the

[1] "Geological Record of the Rocky Mountain Region in Canada," address by the President, GEORGE M. DAWSON, *Bulletin of the Geological Society of America*, Vol. XII, 1901, pp. 57–92.

[2] Pre-Cambrian.

Province of Quebec, and the associated gneisses resemble the Fundamental Gneiss of the same region. The greatest thickness of the Shuswap rocks so far measured, where there is no suspicion of repetition, on Kootenay Lake, is about 5,000 feet, but even here there are doubtless included considerable intercalations of foliated eruptives.

Schrader[1] describes certain granites and schists seen in a reconnaissance along the Chandler and Koyukuk rivers of Alaska. These are referred to as "basal" and certain of the schists are correlated with Spurr's Birch Lake series of schists, but no attempt at further correlation is made.

Brooks[2] describes the Archean of the Tanana-Yukon divide. A broad belt of crystalline rocks extends in a northeast-southwest direction in the region of the Tanana-Yukon divide, embracing a series of gneisses, mica-schists, basic schists, and various intrusives, chiefly of an acid character. Near the middle Tanana this series bends to the west and south, and its continuation is to be sought for in the region of the upper Kuskokwim. To the southeast this belt is probably continued by the granitic rocks on the Pelly River, described by Dawson. What evidence we have goes to show that this is the basal series of the Yukon Basin, and as it contains no recognizable detrital material it can properly be assigned to the Archean. Whatever the original character of the rocks may have been, they are now essentially mica-schists and gneisses, with considerable intrusive material. Their metamorphic condition is the strongest argument for considering them older than any of the sedimentary rocks.

Comstock[3] reviews the stratigraphy of Arizona. Granites, gneisses, and schists, probably of pre-Cambrian age, occur at

[1] "Preliminary Report on a Reconnaissance along the Chandler and Koyukuk Rivers, Alaska, in 1899," by F. C. SCHRADER, *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part II, 1901, pp. 441–86; with sketch map.

[2] "A Reconnaissance from Pyramid Harbor to Eagle City, Alaska, Including a Description of the Copper Deposits of the Upper White and Tanana Rivers," by A. H. BROOKS, *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part II, 1901, pp. 331–91; with sketch map.

[3] "The Geology and Vein Phenomena of Arizona," by T. B. COMSTOCK, *Trans. Am. Inst. Min. Eng.*, Vol. XXX, 1900, pp. 1038–1101.

various places, but have not been thoroughly studied. The massive granites are exposed in a limited tract surrounding Prescott, including Granite Mountain, and farther southwest in the Grand Canyon of the Colorado, in the valley of the Colorado in Yuma county, and in the Little Dragoon Mountains, Cochise county. These massive granites form a basement for the other rocks of the region.

In a number of places are found fissile granites which appear to lie between the massive granites and the schistose strata which form the floor of much of the area of western Arizona.

Schists are well exposed in northwestern Arizona, in Mohave county, with E.-W. strike, tilted at high angles. Very similar exposures occur in other districts, as near Oracle and Mammoth, in Pinal county; in tracts in Pima county, and in portions of Yuma county. In Graham and Cochise counties, and, to a less extent, in Gila county, with occasional outcrops near the adjoining boundary of Maricopa and Yavapai counties, the same trend is prominent. Erosion has exposed portions of the same terrane, thrown into the N.E.-S.W. trend, in limited areas in Graham and Yavapai counties, and, possibly, in the northeast portion of Yuma county.

Blake[1] describes the salient features of the geology of Arizona. The Santa Catalina, Rincon, and Rillito mountains consist largely of granitic gneisses and schistose rocks of pre-Cambrian age with a highly complex folded structure, and exhibiting a high degree of metamorphism. Taken together, these mountains may be regarded as the main axis of ancient uplift, and of insular land areas in the pre-Cambrian and Paleozoic periods, the beginning of the "Arizona Land."

The gneiss of the southern side of the Santa Catalina near Tucson is regarded as Archean. It is remarkable for its regularity of stratification and its great thickness, probably over 10,000 feet. It occurs in great tabular masses made up of thin layers which, when seen laterally, give the appearance of evenly strati-

[1] "Some Salient Features in the Geology of Arizona with Evidences of Shallow Seas in Paleozoic Time," by WILLIAM P. BLAKE, *American Geologist*, Vol. XXVII, 1901, pp. 160–67.

fied shales and sandstones. In the same range, but on the northeastern side, facing the valley of the San Pedro, another formation of thinly bedded and highly crumpled mica schist in sharply defined zigzag folds is referred to the Huronian, and is given the name Arizonan.

Hershey[1] describes the schistose rocks of the Klamath Mountains in northwestern California. On the whole it seems impracticable to fix upon any particular part of the time between the Archean and the Devonian as the period of deposition of the Klamath schists, but it is believed that the evidence favors the earlier or Algonkian portion rather than the Cambrian or Silurian portion.

Spencer[2] describes Algonkian rocks occurring in the center of the Rico Mountains of Colorado. They consist of quartzites, quartzitic schists, and biotite and actinolite schists. The exposed thickness of the quartzites is over 350 feet and probably as much as 500 feet. The relations of the quartzites to the schists have not been ascertained. The schists and quartzites of this area are similar in every way to the series of rocks exposed in the upper part of the Animas Canyon and in adjacent portions of the Quartzite or Needle Mountains, where they have been referred to the Algonkian by Emmons and Van Hise. The quartzite of the Rico Mountains is directly along the strike of the great quartzite belt in the Animas Canyon and Needle Mountain area.

Jaggar,[3] in connection with the discussion of the laccoliths of the northern Black Hills, incidentally refers to the structure of the Algonkian. Its lamination abuts abruptly against the hard basal Cambrian quartzite or the conglomerate, and has a fairly uniform strike of north-northwest. The Algonkian surface is seen to be warped.

[1] "Metamorphic Formations of Northwestern California," by OSCAR H. HERSHEY, *American Geologist*, Vol. XXVII, 1901, pp. 225–45.

[2] *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part II, 1901, pp. 37–78; with geological map.

[3] "The Laccoliths of the Black Hills," by T. A. JAGGAR, JR., *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part III, 1901, pp. 171–303.

Hills[1] describes the geology of the Walsenburg Folio of Colorado.

The principal mass of the Greenhorn Mountains consists of coarse and fine-grained granites and gneisses, hornblende, mica, and chlorite-schist, and subordinate masses of garnet-and epidote-schist, and occasional vein-like bodies of coarse pegmatite. The schistose rocks are more prominent at the southern extremity of the mountains than elsewhere, while the granite and gneissic rocks are more prominent in the main mass toward the culminating point.

Their origin probably dates back to the Archean period. No further correlation is attempted.

Watson[2] describes the granitic rocks of the Piedmont Plateau of Georgia and concludes that they were not all contemporaneous in origin. Some of them are pre-Cambrian, while others may possibly be later in age. However, the youngest acid intrusives could not have been later than, if as late as, the last great Appalachian disturbance or uplift.

Kemp, Newland and Hill[3] further discuss the geology of Hamilton, Warren and Washington counties, extending the observations noted in previous reports to the west and south.[4] The additional points of interest are the occurrence of anorthosites in Johnsburg, in Warren county, the southernmost exposure yet known in the eastern mountains, and "the increasing certainty of the existence of sedimentary gneisses in Fort Ann and Johnsburg townships."

[1] "Walsenburg Folio, Colorado," by R. C. HILLS, *Geol. Atlas of the U. S.*, No. 68, 1900.

[2] "The Granitic Rocks of Georgia and their Relationships," by THOMAS LEONARD WATSON, *American Geologist*, Vol. XXVII, 1901, pp. 199-225.

[3] "Preliminary Report on the Geology of Hamilton, Warren and Washington Counties," by J. F. KEMP, D. H. NEWLAND, and B. F. HILL, *Eighteenth Ann. Rept. State Geologist of New York*, published in *Fifty-second Rept. N. Y. State Museum*, Vol. II, 1900, pp.141–62; with geological maps.

[4] For general discussion of classification of geology of these counties see *Rept. of the New York State Geologist* for 1897, published in *Fifty-first Ann. Rept. New York State Museum*, Vol. II, 1899, pp. 499–553. Summarized, JOUR. GEOL., Vol. IX, 1901, p. 444.

Smyth[1] maps and describes the geology of the crystalline rocks in the vicinity of the St. Lawrence River in the towns of Alexander, Clayton, and Theresa, in Jefferson county, together with portions of Rossie and Hammond in St. Lawrence county. The crystalline rocks of the district are discriminated on the map as granite, granite-gneiss, granite-gneiss with much schist and quartzite, schists and quartzites with much granite-gneiss, schists and quartzites of limestone series, and crystalline limestone. This classification indicates the close association of the various rocks in the field. Under the term schists are classed a variety of rocks, such as quartzite, hornblende and mica schists, hornblende, pyroxene, and mica gneisses, etc., of both igneous and sedimentary origin. The gneiss formation is not a unit, but rather a complex, so far as age is concerned. It is the most widespread of the pre-Cambrian rocks. There is abundant evidence that the granite and granite-gneiss are for the most part younger than the schists and quartzite. The granite has a close genetic relation to the granite-gneiss and is identical with a part of the latter. The granite may be the youngest member of the granite-gneiss complex. The quartzite may have a thickness as great as 500 feet.

Kemp and Hill[2] report progress of work on the pre-Cambrian formations in parts of Warren, Saratoga, Fulton, and Montgomery counties.

Cushing[3] maps and describes the geology of Rand Hill and vicinity, Clinton county. The basal rocks are gneisses of the Dannemora formation occurring in the southwestern portion of the area. These are of doubtful origin, but probably mostly

[1] "Geology of the Crystalline Rocks in the Vicinity of the St. Lawrence River," by C. H. SMYTH, JR., *Nineteenth Ann. Rept. State Geologist of New York*, published in *Fifty-third Ann. Rept. N. Y. State Museum*, Vol. I, 1901, pp. 185–204; with geological map.

[2] "Pre-Cambrian Formations in Parts of Warren, Saratoga, Fulton, and Montgomery Counties," by J. F. KEMP and B. F. HILL, *Nineteenth Ann. Rept. State Geologist of New York*, published in *Fifty-third Ann. Rept. N. Y. State Museum*, Vol. I, 1901, pp. 121–135; with geological maps.

[3] "Geology of Rand Hill and Vicinity, Clinton County," by H. P. CUSHING, *Nineteenth Ann. Rept. State Geologist of New York*, published in *Fifty-third Ann. Rept. N. Y. State Museum*, Vol. I, 1901, pp. 139–182; with geological map.

igneous. Intrusive in them are undoubted igneous rocks—gabbro, anorthosite-gabbro, augite-syenite, syenite and dikes of syenite and diabase.

C. K. LEITH.

MADISON, WIS.

THE *Summary Report of the Geological Survey Department of Canada* for the year 1901 is a paper-bound volume of 270 pages, giving a concise outline of the work done during the year. The volume is issued in order to give to the public, without delay, the results of the year's investigations in different parts of the Dominion. The rapidly increasing mining industry of the country makes it very desirable that the information in possession of the Survey should be immediately available, whereas the full annual reports are, as a rule, two or more years behind the field work. During the last three years the Canadian Survey has lost a number of its men by death and resignation. The death of Dr. G. M. Dawson, late director, was a severe loss, and the resignation of such men as J. B. Tyrrel, A. P. Low, J. McEvoy and R. W. Brock leaves places which the younger appointees are not yet able to fill. Dr. Robert Bell, formerly deputy director, has been appointed acting director. The present staff numbers fifty-four.

During the year 1901 thirty-one parties were in the field, and work was done in each of the seven provinces and in the territories of Alberta, Yukon and Keewatin. R. G. McConnel and Joseph Keele continued the work in the Yukon field. Considerable searching has been done in the hope of finding the lodes from which the gold of the placers was derived. Auriferous quartz veins cut the igneous and clastic schists which are so abundant in the Yukon valley. As a rule, the veins, though numerous, are too small and discontinuous to warrant mining operations. The schists are also auriferous in places. R. A. Daly acted as geologist with the Canadian commission co-operating with the United States commission in locating the British Columbia section of the international boundary. The predominant rocks of the Coast Range were found to be metamorphic sediments, of which but few strata were fossiliferous. The mountain forms are regarded as erosional rather than constructional. Erosional features characteristic of the work of Alpine glaciers—cirques, cols, rock basins, ampitheaters, and deep re-entrants—are abundant. The existing glaciers are small, and there is no indication of general glaciation having prevailed in the belt. R. W. Brock worked in the

Boundary Mining District of British Columbia. The rocks of the district are largely eruptives and intrusives, consisting of greenstones, granites, tuffs, and lava, though older sediments, consisting of limestones, argillites, quartzites, and other metamorphic rocks have been caught up and included in the igneous flows. The region is wholly within the area covered by the Cordilleran ice sheet. The striæ show that the movement was mainly S. 30° E. Assorted glacial materials are very abundant, and terracing is very prominent, often reaching a height of 2,000 feet above the present valley levels. The ore bodies are of large size, but irregular in form and usually of low grade. They occur in all rocks except the newest, and mineralization has extended, with gradually decreasing richness, far into the country rock. Deposits within the limestones or the greenstones and at the contact of the two, are of most frequent occurrence. The vein minerals are chiefly magnetite, pyrrhotite, chalcopyrite, marcasite, arsenopyrite, and micaceous hematite, with more or less galena, sphalerite, and molybdenite. Magnetite is never abundant where pyrrhotite is prominent. The values are principally in copper, gold, and silver. The smelters at Grand Forks and Greenwood have been working steadily, but the pyritic smelter at Boundary Falls has not yet been blown in. W. W. Leach continued the examination of the Crow's Nest coal fields, which lie on the eastern border of British Columbia. The main area covers about 230 square miles, has twenty-two distinct seams with a total thickness of 216 feet, of which 100 feet is workable coal of excellent quality. The smaller, or Green Hills area, covers about seven square miles and contains 79 feet of workable coal in seven seams. L. M. Lambe resumed his work on the Cretaceous rocks of the Red Deer River, Alberta, and succeeded "in securing a large collection of chelonian, dinosaurian, crocodilian, fish, primitive mammalian, and other vertebrate remains of considerable value." Two Chelonians — *Trionyx foveatus* and *Trionyx vagans* — are figured and described. William McInnes worked on the pre-Cambrian formations between Lakes Superior and Manitoba. "The primary object of the season's work was to trace with greater accuracy the Sturgeon Lake gold-bearing belt and to work out the geology of an area lying to the southeast of the eastern half of Lac Seul." All of the important Huronian areas of this region are now mapped. Some promising mineral lands are being developed. A. W. G. Wilson spent the summer in the region west of the Nipigon river and lake. The rocks of the area studied belong to the Laurentian, Huronian, and Animikie

series. The Laurentian rocks consist of gneisses and granites with some schists; the Huronian, of ferruginous quartzite interbanded with hematite of good quality and varying in character from soft red to specular. The Animikie formation is the most widespread. A deep red dolomite, varying from a rather heavy bedded, compact, fine-grained rock to a coarser shaly variety, is the most important lithological unit. Associated with the dolomite is a highly ferruginous dolomitic sandstone which locally carries angular masses of quartz. Conformably overlying the red dolomite, on the Upper Spruce river, is a fine-grained, non-fossiliferous, greenish-gray shale, which is capped by fifteen feet of trap. Trappean flows, probably gabbroid, occasionally reaching a thickness of 300 feet, overlie the sediments for the most part, but are in places interbedded with them. In the eastern half of the Nipigon area the Huronian schists pass into jasper and hematite and form three iron ranges, one north and two south of Sturgeon river. Animikie traps are abundant in this area, and show about the same relations to the sedimentary series as in the western half. The explorations of D. B. Dowling in the region to the west of James bay have shown that the Paleozoic area beginning at the southern extremity of James bay extends uninterruptedly along the coast to cape Churchill in Lat. 59° N. The rocks of the newly explored area in the angle between James and Hudson bays are of Silurian age. To the southwest of Cape Henrietta Maria is a considerable area of Animikie rocks consisting of ferruginous slates and jaspers capped by trap.

Work in the vicinity of Lake Abitibi near the Ontario-Quebec boundary resulted in the more accurate mapping of the pre-Cambrian rocks. A. E. Barlow has added many important details to the reconnaissance work done in Denison, Graham and Creighton townships of the Sudbury mining region in 1890. The unaltered rock of the nickel-copper deposits is a quartz-hypersthene-gabbro or norite. The pyrrhotite, chalcopyrite, and pyrite were original constituents of the magma. In the process of slow cooling of these norite masses a species of differentiation resulted in the segregation of the sulphides "so that the final solidification saw the ore-bodies under very much the same conditions as at present obtain." Associated with the norite in the ore-bearing ranges are micropegmatites which are undoubtedly differentiated portions of the nickel-bearing eruptive, as there is a perfect transition from one rock type to the other. There are three distinct bands of the norite and associated micropegmatites. Of these

the southern, having a length of thirty-two miles and an average width of two miles, is the most important, though the others are not without promise. F. D. Adams returned to his work in the pre-Cambrian area of eastern Ontario. Two maps, covering about 4,200 square miles, have been prepared. The northern half of the area is occupied by granite-gneiss (probably equivalent to Logan's fundamental gneiss) while the rocks of the southern area are chiefly ancient sediments, largely limestones, resting on the gneissic series, but invaded, brecciated, and altered by it. Bathylithic masses of gneiss occur in both the granite-gneiss and the ancient sedimentary areas. In the southeastern portion of the area, associated with comparatively unaltered limestones, are masses of amphibolite and other foliated rocks, with an occasional band of conglomerate. The nepheline syenite of the southern portion of the area seems to have some genetic connection with the limestones and with the granites. Intrusions of gabbro are found associated with the amphibolites. In southwestern Ontario, R. Chalmers made a reconnaissance survey of the superficial deposits, and has recorded some observations relative to recent changes of the level of Lakes Huron and Erie. He also gathered data bearing on the salt, oil, and gas industries of that part of the province. In eastern Ontario R. W. Ells has made a re-survey of the Paleozoic formations about Kingston with a view to determining the age of certain limestones and shaly and arkose sandstones forming the basal strata of the sedimentary series. Murray (*Geological Survey of Canada*, 1852–3) regarded the limestones as of Black River age and the sandstones as of Potsdam. The apparent conformity of the two led later workers to suggest that the sandstones were a local development of the Black River. Ells finds abundant proofs of the Black River age of the limestones. As to the sandstones, though no conclusive proofs were found, he inclines to the view of Murray. He gives brief notes on the economic products of the area. Of these the more important are iron, mica, feldspar, marl, and building-stone. The Survey has planned the careful petrographical study of the rocks of the range of volcanic hills which crosses the St. Lawrence valley in the vicinity of Montreal. O. E. Le Roy has completed the work on Rigaud Mountain and is at work on the rocks of Beloeil. Dr. Adams will soon publish a description of Mount Johnson, and he and Professor Harrington are at work on the petrography of Mount Royal. J. A. Dresser finds Shefford Mountain to be composed of essexite, nordmarkite, and pulaskite. Work on Anticosti island confirms the general features of

the report of Richardson in 1856, and the account in the *Geology of Canada*, 1863. Abundant evidence shows that the island is gradually rising. Professor Bailey continued his work on the Paleozoic rocks of southern New Brunswick. Some areas west of St. John river, formerly mapped as Ordovician, on lithological grounds, are found to contain a rather meager Silurian fauna. Similar areas east of the river are probably of the same age. A systematic examination of the Carboniferous strata of New Brunswick, with a view to the discovery of workable coal has not afforded satisfactory results. Some reconnaissance work was done in Prince Edward Island by L. W. Watson. H. Fletcher finds that the sedimentary rocks about the Basin of Mines include representatives of all the Paleozoic groups and the Triassic and the Pleistocene. Igneous rocks are abundant, and include the Triassic traps and the intrusive masses of gray granite and gray diorite. The examination of the outcrops of the Horton series has failed to afford data by which its true position could be determined. It is evident, however, that it is below strata corresponding to the Keokuk-St. Louis. But some would place it near the base of the Devonian. E. R. Fairbault worked on the structural geology of the Cambrian gold-bearing slates and quartzites. The auriferous quartz veins in the area examined follow the contact of the bedded slates and quartzites. In places the folding has caused the development of saddle reefs, but the larger number of veins are on the limbs of the anticlines. G. F. Matthew presents in tabular form the results of his study of the Cambrian rocks of Cape Breton. He shows the completeness of the Cambrian record of the maritime provinces and correlates the formations with those of Great Britain. Extended notes are added on the particulars of the faunas. Dr. Hoffman reports briefly on the chemical and mineralogical work of the Survey. The substantial progress of the mineral industries is shown in the report of E. D. Ingall. A very valuable feature of the report is the index maps of the various provinces showing the areas covered by the various maps published and in preparation, and giving dates of the reports in which the areas are described. J. F. Whiteaves reports on the work in Paleontology.

Some of the individual reports seem to indicate lack of experience both in the prosecution of the field work and in the preparation of the report. The smallness of the parties and the large areas covered by some of them, make it impossible to do more than hasty reconnaissance work.

R. D. GEORGE.

Bibliography and Catalogue of the Fossil Vertebrata of North America. By OLIVER PERRY HAY. Washington: Bulletin of the United States Geological Survey, No. 179, 1902. Pp. 868.

VERTEBRATE palæontologists, not only of America, but of the world, are under obligations to Dr. Hay for his very useful bibliography and catalogue of North American fossil vertebrates. Only he who has attempted something of the sort, or who has toiled for many hours trying to find what Cope has written upon some given subject — and there are few subjects in vertebrate palæontology that he has not written about — will appreciate, not only the vast amount of painstaking labor that has been involved in the production of the work, but also its value as a time saver. The work is as complete and accurate as any one could expect it to be. Very few American papers are omitted, so far as the writer can discover, and he has discovered but few wrong references, not as many as might be expected from the mere mechanical execution of the book and its proofreading. The work is an indispensable necessity for every student of vertebrate palæontology, for which he can not be too grateful; and it is much more than the title indicates.

There are some, however, who will not wholly agree with the author in the many changes he has made in nomenclature — changes that are not always consistent, but which, while detracting somewhat from the usefulness of the work as a guide, do not affect it as a tool. Such long-established names as *Ichthyosaurus*, *Pterodactylus*, *Mastodon*, *Dicotyles*, *Oreodon*, *Lacertilia*, *Ophidia*, etc., have been ruthlessly decapitated on the score of priority, which sometimes, as in the case of *Pterodactylus*, is a little strained. The older French writers persistently transformed technical zoölogical terms into the vernacular, and doubtless Cuvier intended *Pterodactylus* as the name of the flying reptiles. *Basilosaurus*, though expressing a falsehood, and contrary to the best canons of nomenclature, he accepts in place of the well-known *Zeuglodon*. He refuses to accept *Dinocerata* in place of the wrongly-formed *Dinocerea*, though the latter term was rejected by its author, and yet changes *Toxochelydæ* into *Toxochelyidae*. He accepts *Deinodon* as distinct from *Dinodon*, but rejects *Deinosauria* in favor of *Dinosauria*. As a purist and priorist he goes too far, and becomes involved in difficulties, as is always sure to be the case. Surely it is allowable to correct manifestly wrongly spelled or wrongly Latinized names. But these opinions of the author one need not follow unless he chooses, and he has done a service in calling attention to these trivial but annoying matters of

dispute. One does not always see how the author has been guided in the selection of papers by foreign writers. From the list of over one hundred titles of papers published by Smith Woodward prior to 1900, sixty-nine are recorded. We can only be thankful that so many are given.

The geological survey is to be congratulated upon the publication of the work; but we cannot help wishing that the printer had left the leaves untrimmed.

S. W. W.

Evolution of the Northern Part of the Lowlands of Southeastern Missouri. By PROFESSOR C. F. MARBUT. *The University of Missouri Studies*, Vol. I, No. 3 (Columbia), July, 1902. viii + 63 pages; plates I–VII.

THE paper is of more than usual interest to physiographers in that it presents in a comprehensive way the history of an extremely interesting locality. It is divided into Parts I and II, the former treating of the geography and geology of the region, and the latter of its physiographic development.

The writer abandons his former ideas of the origin of Crowley's Ridge,[1] and agrees, in the main, with the views of Dr. Branner, published several years ago, while state geologist of Arkansas.[2] It is shown that the lowland north and west of Crowley's and Benton Ridges, which is spoken of in the paper as the Advance lowland, was formed by the Mississippi at a time when it turned westward at the present site of Cape Girardeau and flowed past Delta, Poplar Bluff, and Neelysville, Mo., and Pocahontas, Powhattan, and Newport, Ark. While the Mississippi was forming the Advance lowland, the Ohio was eroding the broad valley between the eastern edge of Crowley's Ridge and the uplands of western Tennessee, and which the author calls the Cairo lowland.

While the Mississippi is the larger of the two streams, it has twice been captured by the Ohio. The capture of the larger stream by the smaller was made possible by the latter having the lower flood plain. The first capture was effected by a small tributary of the Ohio, working its way headward, through what was then a continuous ridge separating the two great rivers, along or near the present course of Little River; the second, by another small tributary working its way northward from

[1] *Proc. Bos. Soc. Nat. Hist.*, Vol. XXVI (1895), pp. 479–88.

[2] *Ann. Rep. Geol. Sur. Ark.*, Vol. II (1889), preface, p. xiv.

the present site of Commerce to where Gray's Point now stands. As a result of this, the Mississippi abandoned the Advance lowland at its eastern end and assumed its present course.

Other cases of capture of smaller streams are described in detail, which make interesting reading for the student of physiography.

The time of the lowland formation was the interval between the first and second glacial epochs.

Altogether it is an admirable piece of work. There are two points of courtesy, however, upon which the paper is open to some criticism: The discrediting of the published views of Dr. Branner upon the subject of the paper, and the underestimating of the maps of the region, published by the Mississippi River Commission. When in 1895 the author advocated a different theory regarding this drainage,[1] Branner's views were duly considered and promptly upset; now that Branner is found to be correct, his theory of the origin of Crowley's Ridge is spoken of as being "merely a statement of the popular view." The true theory of the ridge's history may be the popular one in Missouri, but the present writer has reason to believe that it is not the popular one in Arkansas even today. Again, Professor Marbut says that Dr. Branner's statements "lay no claim to scientific completeness." This is true; but it should be noted that Dr. Branner published his ideas, not in the body of the report on Crowley's Ridge, but in the preface to the report. The report itself was written by Professor Call, an assistant on the Arkansas Geological Survey, with whose ideas as to the origin of the ridge Dr. Branner did not agree; and not agreeing, justice to himself required him to say so, but at the same time good taste and expediency forbade a full discussion of the matter at that time and place. The present writer happens to know that the data collected by the late Arkansas survey on the history of Crowley's Ridge would fill a good-sized volume. While Dr. Branner's treatment of the subject made no pretense of being exhaustive, his statements were based upon a large amount of data at his command. The author likewise says that when he undertook the work on the region "no sort of topographic map of this part of the lowlands was in existence." The map published with the Crowley's Ridge report of the Arkansas Geological Survey, and the map of the Mississippi River Commission from which the Arkansas map was largely compiled, so far as their portrayal of the physiographic history of the region goes, are in all essen-

[1] *Loc. cit.*

tials relating to the questions discussed, like that published by Professor Marbut, Plate VI of his paper.

Again, the present writer wishes to express his appreciation of Professor Marbut's paper as an interesting and detailed account of physiographic changes, the main features of which were already known.

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Ensayo de una bibliografia historica i jeografica de Chile. Por NICOLAS ANRIQUE R. I L. IGNACIO SILVA A. Santiago de Chile. 1902. 8vo, xix + 679 pages.

THIS work is of the first importance to all students of the history, geography, and geology of Chile. It contains 2,561 titles, to many of which are added brief but valuable annotations. The bulk of the works listed are in the Spanish language, but there are many in German, French, and English. The first 996 titles relate to the history of Chile; the remaining 1,565 relate to its geography, including topography, hydrography, seismology, meteorology, travels, geology, paleontology, and mineralogy. The introduction to the second part contains a sketch of the physical geography of Chile. The author observes that the number of Chilean volcanoes has been greatly exaggerated. A list of them is given, with their latitudes, elevations, and dates of last eruptions. This list mentions forty volcanoes, for several of which no eruptions have been reported. The second part of this introduction devotes eleven pages to the meteorology and climate, under which are included earthquakes, the most important of which are listed. The third part of the introduction treats briefly of ethnographic geography. In spite of numerous oversights and omissions this is one of the most valuable publications made of late years in Chile and it is to be hoped that it will be turned to abundant account by our students of both political and natural history.

J. C. BRANNER.

STANFORD UNIVERSITY,
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